Improvement of Flood Risk Assessment under Climate Change in Ho Chi Minh City with GIS Applications

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Entwicklung des Hochwasserrisikos beeinflusst durch den Klimawandel in Ho Chi Minh Stadt mittels GIS

Von der Fakultät für Umweltwissenschaften und Verfahrenstechnik der Brandenburgischen Technischen Universität Cottbus zur Erlangung des Akademischen Grades eines Doktors der Philosophie (Ph.D.) in Umweltwissenschaften genehmigte Dissertation

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Declaration/ Affiant

The following Philosophy of Doctor thesis was prepared in my own words without any additional help. All used sources of literature are listed at the end of the thesis.

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Cottbus, December 17 2013 Tran Thong Nhat

Dedication

The first dedication is given my parents who always wish their children attaining further steps in the way of human knowledge. I also want to dedicate the thesis to my son who usually play and make obstreperousness beside as I did the research. The final I would like to dedicate to my wife who always suggests a lot of strange ideas and sometimes cooks for a funny meal

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List of Abbreviations

Abbreviation	Full Descriptions
2D	Two Dimensions
3D	Three Dimensions
ADB	Asian Development Bank
AGC-DOST	Applied GIS Center - Department of Science and Technology
BFCI-DARD	Bureau of Flood Control and Irrigation - Department of Agriculture and Rural Development
BMBF	German Ministry of Education and Research
DEM	Digital Elevation Model
DHI	Danish Hydraulic Institute
DTM	Digital Terrain model
ESRI	Environmental Systems Research Institute
FC	FLOODsite Consortium
GDLA	General Department of Land Administration
GPS	Global Positioning System
HCMCPC	Ho Chi Minh City's People Committee
HCMCSO	Ho Chi Minh City Statistical Office
ICEM	International Centre for Environmental Management
ICEM	International Centre for Environmental Management
IND	Industry
IPCC	Intergovernmental Panel on Climate Change
JICA	Japan International Cooperation Agency
LIDAR	Light Detection And Ranging
MONRE	Ministry of Natural Resources and Environment
NSWDOC-MHL	New South Wales Department of Commerce - Manly Hydraulics Laboratory
OGC	Open GIS Consortium
OSP	Open Space
PUB	Public
RES	Resident

SCFC	Steering Center of the urban Flood Control program of Ho Chi Minh city
SF	Structure Forum
SIHYMETE	Sub Institute of Hydrometeology and Environment of South Viet Nam
TIN	Triangle Irregular Network
TL	Tide level
UST	Urban Structure Types
UTM	Universal Transverse Mercator
VNGov.	Vietnamese Government
VNUHCM	Vietnam National University Ho Chi Minh City
WB	World Bank

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Improvement of Flood Risk Assessment under Climate Change in Ho Chi Minh City with GIS Applications

Abstract

Ho Chi Minh City is the largest city in VN. The city is the most important center of economy, society and culture in the southern region of Vietnam. However, due to characteristics of natural conditions with low topography and borders touch the sea so that since the late 20th century with the rapid economic and urban development there are environmental problems have arisen. One of the problems is flooding issue caused by high tide. With these natural conditions and sea level rise of climate change in the future, Ho Chi Minh City is considered as one of the most affected and damaged cities in the world.

Therefore, many policies have been set out from the national to local levels in Vietnam to prepare for adaptability of impacts and risks of the sea level rise and the climate change. And this has also been considered in Ho Chi Minh City as the development policies of the city authorities have to consider in the context of the sea level rise and the climate change. A number of researches have been conducted to assess the impact of climate change to Ho Chi Minh City in the future. However, these researches are still need to be enhanced further.

The flooding problem is a major issue of the sea level rise in Ho Chi Minh City. And to make a good result, the flood model needs a lot of requirements that ensure fine quality of input data, suitable model and a relied procedure. In the available research, the input data is not really the highest quality in the available context in Ho Chi Minh City. As the flood model is implemented, one of the input data requirements of the model is information detail of elevation in the flooded area. And this is more necessary than in geophysical urban areas such as Ho Chi Minh City. And to assess fully flood risk issues for flooding caused by tidal phenomenon in Ho Chi Minh City, the determination of many characteristics of flood model is very useful for users who need to apply the results of the model for the planning development in Ho Chi Minh City in the future. Besides adopting a uniform environment as GIS for managing all the data of flooding problem and making conditions for the development of decision support systems is very necessary for flood management in the future.

The research has been carried out and its results have been generated on the flood risk assessment associated context of the sea level rise due to climate change with high emissions scenario A1FI in 2030 for the current houses, the population and the land use types. The results have shown a lot of the areas where are inundated in the future with the increasing flooding duration, depth and frequency even though they are not flooded at the current because there are some protective structures. This will be helpful for suggesting a forecast of the development direction to decision makers in Ho Chi Minh City for next time period.

And the last part is the proposal for decision and policy makers, authorities and planners as well. Moreover, the results of this research can be used as the references and the foundations for further researches and so that the problems that Ho Chi Minh City may be encountered due to flood risk caused by climate change to the economic and social aspects of the development in Ho Chi Minh City will encounter. And the problem of adaptation to climate change will be more completed and more thoroughly so that it is to minimize the damage of climate change for the city.

Keywords: GIS, Sea Level Rise, Flood Risk, Climate Change, Ho Chi Minh City.

Entwicklung des Hochwasserrisikos beeinflusst durch den Klimawandel in Ho Chi Minh Stadt mittels GIS

Abstrakt

Ho Chi Minh Stadt ist die größte Stadt in Vietnam. Sie ist das wichtigste Zentrum für Wirtschaft, Gesellschaft und Kultur in der südlichen Region Vietnams. Durch den rasanten wirtschaftlichen Aufschwung und die damit einhergehende Stadtentwicklung gibt es seit dem Ende des 20. Jahrhunderts Umweltprobleme. Dies wird durch die natürlichen Bedingungen, eine wenig ausgeprägte Topographie und die Nähe zum Meer begünstigt. Überschwemmungen durch Hochwasser stellen ein großes Problem dar. Mit diesen natürlichen Bedingungen und dem prognostizierten Meeresspiegelanstieg durch den Klimawandel ist Ho Chi Minh Stadt zukünftig als eine der am stärksten betroffenen und geschädigten Städte der Welt zu betrachten.

Daher sind viele Maßnahmen auf nationaler und lokaler Ebene in Vietnam entwickelt worden, um sich den Auswirkungen anzupassen, und den Risiken des Anstieges des Meeresspiegels und des Klimawandels zu begegnen. In Ho Chi Minh Stadt muss das aufgrund der oben genannten Bedingungen besonders betrachtet werden. Eine Reihe von Untersuchungen wurden durchgeführt, um die Auswirkungen des Klimawandels in Ho Chi Minh Stadt in der Zukunft zu beurteilen. Allerdings müssen diese Untersuchungen noch weiter entwickelt und verbessert werden.

Das Überschwemmungsproblem durch den Anstieg des Meeresspiegels, ist ein wichtiges Thema in Ho Chi Minh Stadt. Um ein gutes Ergebnis zu bekommen, müssen die Qualität der Eingangsdaten sowie das Modell gut sein. In der derzeitigen Forschung, haben die Eingangsdaten nicht die höchste Qualität im Kontext von Ho Chi Minh Stadt. Als das Hochwassermodel implementiert wurde, war eine der Eingangsdatenanforderung des Modells, die Information der Höhe der Überschwemmung. Dies wird in städtischen Gebieten noch wichtiger aufgrund der geophysikalischen Gegebenheiten von Ho Chi Minh Stadt.

Für eine umfassende Beurteilung der Hochwasserrisikofragen von Überschwemmungen beeinflusst zusätzlich durch die Gezeitenphänome in Ho Chi Minh Stadt , ist die Bestimmung vieler Eigenschaften für die Ergebnisse des

Hochwassermodells sehr nützlich für Anwender, die die Ergebnisse des Modells für die Planung der Entwicklung in Ho Chi Minh Stadt in der Zukunft anwenden werden. Hierfür wäre die Einführung einer einheitlichen Umgebung im GIS zur Verwaltung aller Daten von Überschwemmungsproblemen und Herstellungsbedingungen für die Entwicklung von Entscheidungsunterstützungssystemen in der Zukunft für das Hochwassermanagement sehr wichtig.

Vorliegende Arbeit hat Ergebnisse in Bezug auf Hochwasserrisiko basierend auf dem Emissionsszenario A1FI im Jahr 2030 , verbunden mit dem darin prognostizierten Anstieg des Meeresspiegels, für die aktuelln Bebauung, Bevölkerung und Landnutzungstypen generiert. Die Ergebnisse zeigen eine Menge Bereiche, in denen in Zukunft mit zunehmender Überschwemmungsdauer, -tiefe und -frequenz gerechnet werden muss, auch wenn sie aktuell nicht überflutet werden, da sie einige noch Schutzstrukturen besitzen. Dies wird hilfreich für Prognosen der weiteren Entwicklung für Entscheidungsträger in Ho Chi Minh Stadt in der nächste Zeit sein.

Zusätzlich bietet der letzte Teil der Arbeit einen Vorschlag für die Entscheidungsfindung der Entscheidungsträger, Behörden und Planer. Darüber hinaus können Ergebnisse dieser Forschung, sowie Referenzen und Grundlagen, für weitere Forschungen verwendet werden, so dass den Problemen in Ho-Chi-Minh-Stadt aufgrund des Hochwasserrisikos, beeinflusst durch Klimawandel und die damit verbundenen wirtschaftlichen und sozialen Aspekte, begegnet werden kann. Dadurch kann das Problem der Anpassung an den Klimawandel angegangen weden, so dass der Schaden des Klimawandels für die Stadt minimiert werden kann.

Stichwort: GIS, Anstieg des Meeresspiegels, Hochwasserrisiko, Klimawandel, Ho Chi Minh Stadt, Vietnam

Chapter 1. Introduction

Climate change is a global problem and human has to face. Climate change has also been performing that its impacts are very serious to Viet Nam. All reports that have researched on climate change list Viet Nam as a greatly affected countries of climate change because of its topography and geography (WB, 2007). The most terrible issue is rising of sea level.

The impacts of climate change affect the areas located along the coast stretching from north to south of Vietnam. One of the most important city and it severely affected that is Ho Chi Minh City (HCMC).

With the high concentration of population and demands for housing, many areas in Ho Chi Minh City have been excessive urbanization and land use changes dramatically not only in the central area but also in the surrounding rural areas. This has created problems about environment. One problem is the phenomenon that occurs frequently flooded over the city.

Research, Improvement of Flood Risk Assessment under Climate Change in Ho Chi Minh City with GIS Applications, is seen as a part of a research project, Megacity City Research Project. Ho Chi Minh - Integrative Urban and Environmental Planning Adaptation to Climate Change Framework, conducted by the Brandenburg University of Technology Cottbus - Senftenberg. The project is a part of the research program "Sustainable Development of the Megacities of Tomorrow - Climate and Energy Efficient Structures in Urban Growth Centres", has been sponsored by the German government, Ministry of Education and Research (BMBF).

1. Statement of problem

According to official web site of Ho Chi Minh City People’s Committee (HCMCPC, 2010), Ho Chi Minh City is “located from 10°10’-10°38’ north and 106°2’-106°54’ east. The city center is 50km from the East Sea in a straight line. Ho Chi Minh City belongs to a transitional region between the southeastern and Mekong Delta regions. The general topography is that Ho Chi Minh City terrain gets lower from north to south and from east to west. There are three types of terrain. The high terrain lies in the northern-northeastern area and part of the northwestern area encompassing northern Cu Chi, northeastern Thu Duc and District 9. This is the bending terrain with average height of 10-25 meters. Long Binh Hill in District 9 is the highest at 32 meters. The depression terrain lies in the southern-southwestern and southeastern part encompassing district 9, district 8, district 7, Binh Chanh rural district, Nha Be rural district and Can Gio rural district. The area's height is in the range of 0.5 to 2 meters. The medium-height terrain lies in the middle of the city, encompassing most old residential areas, part of districts 2 and Thu Duc district, and the whole of district 12 and Hoc Mon rural district. The area's height is 5-10 meters" and 72.3% of the whole urban area of Ho Chi Minh City is below 2 m mean sea level (Storch, Downes, Thinh, Thamm, Phi, Thuc, Thuan, Emberger, Goedecke, Welsch and Schmidt, 2009).

About hydrology, Ho Chi Minh City is located in the downstream of Dong Nai - Sai Gon river system and there are two large water storage reservoirs including Dau Tieng reservoir connected to the Saigon River and Tri An reservoir connected to the Dong Nai river. Ho Chi Minh City has a network of rivers and canals are very diverse. In addition to the main rivers, the city also has an intricate system of canals such as Lang The, Bau Nong, Rach Tra, Ben Cat, An Ha, Tham Luong, Cau Bong, Nhieu Loc-Thi Nghe, Ben Nghe, Lo Gom, Kenh Te, Tau Hu, Kenh Doi. Sometimes the rivers and the canals serve in irrigation, but are influenced by the fluctuations of regime of semi-diurnal tide from the South China Sea. Tidal penetration in land has caused adverse impacts on agricultural productivity and limits the water drainage in urban areas.

Average rainfall in the city reached 1.949 mm/year. Each year, average number of rain days in the city is 159. The rain days are most concentrated for the months from May to November, accounting for about 90%, especially in the two months June and September. On whole extent of the city, rainfall is unevenly distributed and tends to increase southwest – northeast axis. The core districts and northern districts have a higher precipitation that the other areas.

Since the elements of topography, hydrology and meteorology, it is to see that Ho Chi Minh City from natural conditions is very sensitive to variability and change of climate. Climate change, particularly changes in precipitation, storm intensity and sea level rising will affect Ho Chi Minh City. They are causes of flooding and threaten not only the low land areas, but also extend to other areas.

Besides natural factors, human and social factors are also an issue to regard. The causes of serious problem of urban flooding are the ongoing rapid urbanization process, which has changed the land-use patterns. Ho Chi Minh City has the largest population in Vietnam and its urbanization rate is very high. With the demands of economic development and housing for residents in urbanization progress combining with the weakness in construction control and management the city has loss the green space areas, water bodies and agricultural land that are converted to impervious surfaces rapidly (JICA, 2004; Van, 2008; Viet, 2008). Natural streams, channels, lakes, wetlands and vegetation structures that can maintain the urban water balance have been replaced by impermeable surfaces causing increased surface run-off flow. With state of land use change inappropriately consequently, problems of urban environment have appeared and one of which is a phenomenon of urban flooding.

According to experts, the phenomenon of flooding in Ho Chi Minh City began appearing in the early the 90s of 20th century (Lai, 2005). At the early time, the phenomenon appeared in low frequency and in small areas. However, day to day level of flooding has increased rapidly along with the urban development in Ho Chi Minh City (JICA, 2004; Lai, 2005; Viet, 2008). Even if at the current, the flooding is appearing more and more serious as it is heavy rain and tide and flooding come every month of year (Nhan, 2006; Phi, 2007). Under this situation, the city government has tried to eliminate the flooded sites drastically but the situation has not improved since the old flooded sites disappeared, the new ones come. Therefore, urban flooding in Ho Chi Minh City is already doing a lot of suffering for regions when rain and high tide appear. Urban flooding has made sustainable development plan of Ho Chi Minh City that has been facing many challenges at the current and the future (SCFC, 2010; WB, 2007).

The urban flooding in Ho Chi Minh City can be divided into two groups based on supplying water source to flooding phenomenon. The first is raining and the second is due to difference between water levels of the system of canals and inland elevation in Ho Chi Minh City. In the second group includes the phenomenon of tides, flooding caused the flood discharge in the lakes on the Sai Gon and Dong Nai River upstream making the water level rising in the rivers and canals. The flooding caused by rainfall mainly concentrates for six-month of rainy season from May to November. The flooding caused by the high tide is most serious because it occurs with high frequency in all months. Moreover, regime of semi-diurnal tide in Ho Chi Minh City has caused flooding tide occurring two times per day. For the flooding caused the discharge from the reservoirs, this is not often and it only occurs in heavy rains. But in the fact that the discharge is often not the main cause of the flooding is an enhanced factor for the severity of flooding. Due to the supplying of water resources as the above analysis, the flooding of the first group is called rainfall flooding and the flooding of the second group is called tidal flooding.

In addition to the natural factors cause Ho Chi Minh City became a flood-prone areas due to low land, tide is located in the geography when there are often monsoon rains, the flooding in Ho Chi Minh City is contributed by human activities. Because the natural factors are fixed and existed for long time, but the phenomenon of flooding occurs and becomes severe for around the last two decades. The human causes are factors decide to the nature and extent of the current flooding. In the human factors, the direct factor causing the flooding in Ho Chi Minh City is urbanization that has changed the land-use patterns. Natural streams, channels, lakes, wetlands had been occupied and fill up to be residential areas (Phi, 2009). Consequently, infiltration ability has been reduced a lot and water when it is rain and discharge from reservoirs in river upstream comes would not have places to store for balance of water. Besides, vegetation structures that can maintain the urban water balance have been replaced by impermeable surfaces so that land has been reduced infiltration ability and it causes increasing surface run-off flow. Another factor is the drainage system of Ho Chi Minh City has been very old, obsolete and damaged so that the drainage system has overloaded when it is rain (Phi, 2007; Thang, 2010; Trung, 2009). As a result, when rainfall comes surface flow will not be able to escape for short time and the flooding appears. The extent of the flooding is more severe if the rain is heavy and continues for long time.

Additionally, Ho Chi Minh City is located on a weak stratum and a low relief. That the stratum under this city is very feeble and the rapid urban growth builds resident areas where construct many high buildings and blocks. In the new residential areas, demands of living water are inquired and increased day by day but infrastructure of living water supply can not solve. As a result, the households in the areas have to conduct extraction of groundwater for their needs uncontrollably (Nga, 2006). Combination between the extraction of groundwater and the increasing of impermeable surface has made water table has reduced a much more so that land subsidence has appeared (Dinh, Trung, Sarti, Dransfeld and Hanssen, 2008; Nga, 2006; Trung & Dinh, 2009). After for a period of time, the areas is lower and lower and as a result flooding happens obviously and frequently as flood tide.

Recent studies on the urban flooding problem in Ho Chi Minh City have proven that local impacts of climate change and rising tide levels are coming to Ho Chi Minh City. Especially sea level rising has affected seriously. According to Ho Long Phi (2007), rainfall events which have high precipitation are increasing dramatically for some last recent decades (Table 2.1). In addition a report delivered by Vietnamese Ministry of Natural Resources and Environment (MONRE) in 2009 estimates that sea level rise in the area of Ho Chi Minh City is in the situation of alarming. With average emission scenario by 2050 sea level rising may be up to 33cm and be 75cm at the end of 21st century (Table 2. 2).

Thus the problem of urban flooding in Ho Chi Minh City is related to two following issues:

- Land use change is not suitable having caused more and more serious flooding in Ho Chi Minh City. This situation has affected the lives of people and the urban development in Ho Chi Minh City.
- Additionally, local climate change and sea level rising are coming and happening more clearly so that the flooding situation will be worse in the future.

With the urban development and infrastructure as stated above if Ho Chi Minh City authorities do not have any improvement on management and planning, flooding areas are more serious and deeper from consequences of climate change impacts. Moreover, not only will many flooding areas appear and spread in the near future but also flood risks about environment to habitant living in the areas will issue if authorities do not have any strategies for adaptation and mitigation.

With the problem of urban flooding in Ho Chi Minh City, this research would like to contribute on understanding and clarifying the risks and effects and damage of flooding to current houses, people, and urban systems in the future with sea level rise.

2. Aims and objectives

2.1. Aims

Aims are to show the general targets that researcher yearn toward after the research completes the entire study. In this study there are two goals that are expected to progress:

- To improve the accuracy of results of flood model with optimizing the digital terrain model and determining more flooding characteristics
- To identify and expose the current and future risks of urban flooding to the current houses, population and land use

2.2. Objectives

To achieve the aims, implementation procedure will need to achieve the specific objectives of the various stages towards completion of the aims that had been set. In that sense the objectives of the research will be:

- To improve the digital terrain model for the flood model
- To optimize the flooding characteristics for the flood model
- To produce hazard maps of urban flooding to current houses, population and land use
- To exposure and evaluate future flood risks to current houses, population land use
- To announce and warn to decision makers, planners on a suitable land use planning integrated climate change scenarios
- To give helpful information to people where are safe areas for resettlement under conditions of climate change in the future

3. Significance of the study

Ho Chi Minh City is one of the most major and important center of economic, cultural and education of Vietnam. And the city has the largest population of Vietnam, more than 7 million of people in 2009 (HCMCPC, 2011; Wikipedia, 2013). Ho Chi Minh City is one of the city has a great influence to the economic development for its country. Ho Chi Minh City located in the North of Mekong Delta, and the down stream of Dong Nai river system. This is also a transition area between the southeastern and southwestern regions. This is a traffic hub linking the provinces in the region and the international gateway. Based on that favorable strategic position, the city has been developing rapidly; that can say Ho Chi Minh City is the fastest in Vietnam of all aspects.

In the progress of development and international integration, Ho Chi Minh City has always maintained a central role in economic, financial, trade and services of the country and is the kernel of the southern key region on economy that is one of three largest key economic regions. The city is also a driving force for the social economic development in the southern areas and whole the country for the national strategy of industrialization and modernization. Ho Chi Minh City is keeping the leading role of the economy in Vietnam. The city accounts for 0.6% area and 8.34% populations in Vietnam but accounts for 20.2% GDP in 2009 (HCMCSO, 2011; Wikipedia, 2013).

Because the city is one of the most important centers for the economic development in the southern region and Vietnam, the facing and suffering with urban flooding that occurs regularly and continuously severe have been enforced Ho Chi Minh City in a very difficult situation to ensure the city being able to continue to maintain strong and sustainable growth in the future. Therefore, researches solving environmental problems in the city to make recommendations to decision makers and planners who will deliver policies and spatial planning appropriately to help the city continue to develop steadily will have very important meaning in the moment and the future.

This study is an applied research that applies a new method, geographic information system (GIS), for studying and assessing under influences and impacts of urban flooding in Ho Chi Minh City. It is important and the most significant of this research is the its results will contribute a scientific basis for planning and policy making of the managers who make policies that are appropriate for sustainable development in the future under the impacts of climate change becoming more severe. Additionally, the research will also contribute to flood risk management in the city with the GIS technology.

4. Methodology

In order to assess impact, risk and vulnerability of flooding to Ho Chi Minh metropolitan areas needs digital flooding maps at the time points from the current to future when climate and land use are changed. A flood model has to be evaluated and selected and then it is used to produce digital flooding maps from input data such as elevation, land use, soil, drainage, hydrology and climate data. After the chosen flood model is completed it will be applied to two scenarios: situation of flooding for current urban system and climate conditions, situation of flooding for current urban system and future climate conditions that are impacted by climate change.

In order to choose a suitable flood model easily needs to assess existing situation of flooding in the city of Ho Chi Minh City, the study's requirements and the characteristics of existing flood models. Flooding phenomenon in Ho Chi Minh City can be divided into two types based on water supplying sources caused flooding. They include the first source provided by rainfall or precipitation and the other one provided by the canals due to difference of water levels between water level in canals and ground elevation, called the tide level.

With the first source, the flooding phenomenon is formed as following process. When it is heavy rain, surface flow will occur if rainy water could not infiltrate into soil in rained areas. The surface flow then reaches to drainage network system if it is existential. If the drainage network system can not flow out rivers and canals in the area the rained areas will be flooded locally. After that time the flooded areas will spread into around places. The spreading speed and areas depend on precipitation, rainfall intensity, areas elevation, the drainage network system, land use/ land cover and soil types. The precipitation is an item of climate therefore climate change will effect direct to potential flooded areas in the future.

Differently, the flooding in the situation of tide is different source to supply water and drainage factor. In this case the catch basins and the manholes or the rivers and the canals are the water providers. And then spreading procedures of the water extends over ground surface to around areas. The drainage factor depends on hydrologic system, absorption and infiltration of soil in the area. In reality, the probability of the two reasons occur together is able and consequences of flooding is more serious.

Understanding the causes of flooding in Ho Chi Minh City will help a lot for the selection of flood model consistent with context of the Ho Chi Minh City. At the current there are many flood models on over the world, in general they have been integrated on GIS environment. Therefore, choosing the most appropriate flood model with the flood situation in Ho Chi Minh City is an important step needing to determine. In order to does this step, the first task has to classify the types of flood model nowadays on over the world, then build a set of criteria to select a model that is the most appropriate model with context of Ho Chi Minh City. After that determining the most appropriate model for Ho Chi Minh City done, the model will be used to identify flooded areas and flooding maps. The flooding maps combined with the information of the urban system will expose risk degree at the flooding areas in Ho Chi Minh City. Based on exposure of the degree, some predictions, warnings and suggestions will be sent to policy, decision makers and planners. It is helpful and useful to get up the awareness around policies of adaptation and reducing living costs as the scenarios that are able to happen with the conditions of climate change.

From the analysis of the above factors, a process of the research is described in the flowchart as figure 1. The research process will begin with a review and evaluation indoor about current flood models on over the world. Then the second step will build a set of evaluation criteria for choice the most appropriate flood model in context of Ho Chi Minh City. The next step is to collect data for the research, including data for implementing the model and data for assessing the damage, the impact of flooding. Once data collection is done, analysis will be conducted that founds trends and rules of climate change which will be able to calculate the values of weather in the future. The construction of evaluation criteria for choice the model is based on three aspects: theory to construct models, data input of models and requirements to satisfy the research output.

After the evaluation criteria has completed, the choice of the most flood model will be carried out. To get reliable results after implementation, the model need to conduct calibration validation. The calibration process will be accepted after the validation process gets a high satisfaction. With the calibrated parameters the chosen model will be implemented to identify flooded areas and create flooding maps. The results, flooding maps, will be used to analyze and evaluate the impact and risk to the urban system. The evaluation is based on the spatial relationships. And last step that will be done basing on the assessment of flood impact, risk and vulnerability is predictions, suggestion, recommendations to decision makers and planners. The flooding maps will be produced with 2 scenarios: current climate data and future climate data. And based on the flooding maps assessment of flood risks is carried out for the current houses, population and land use.

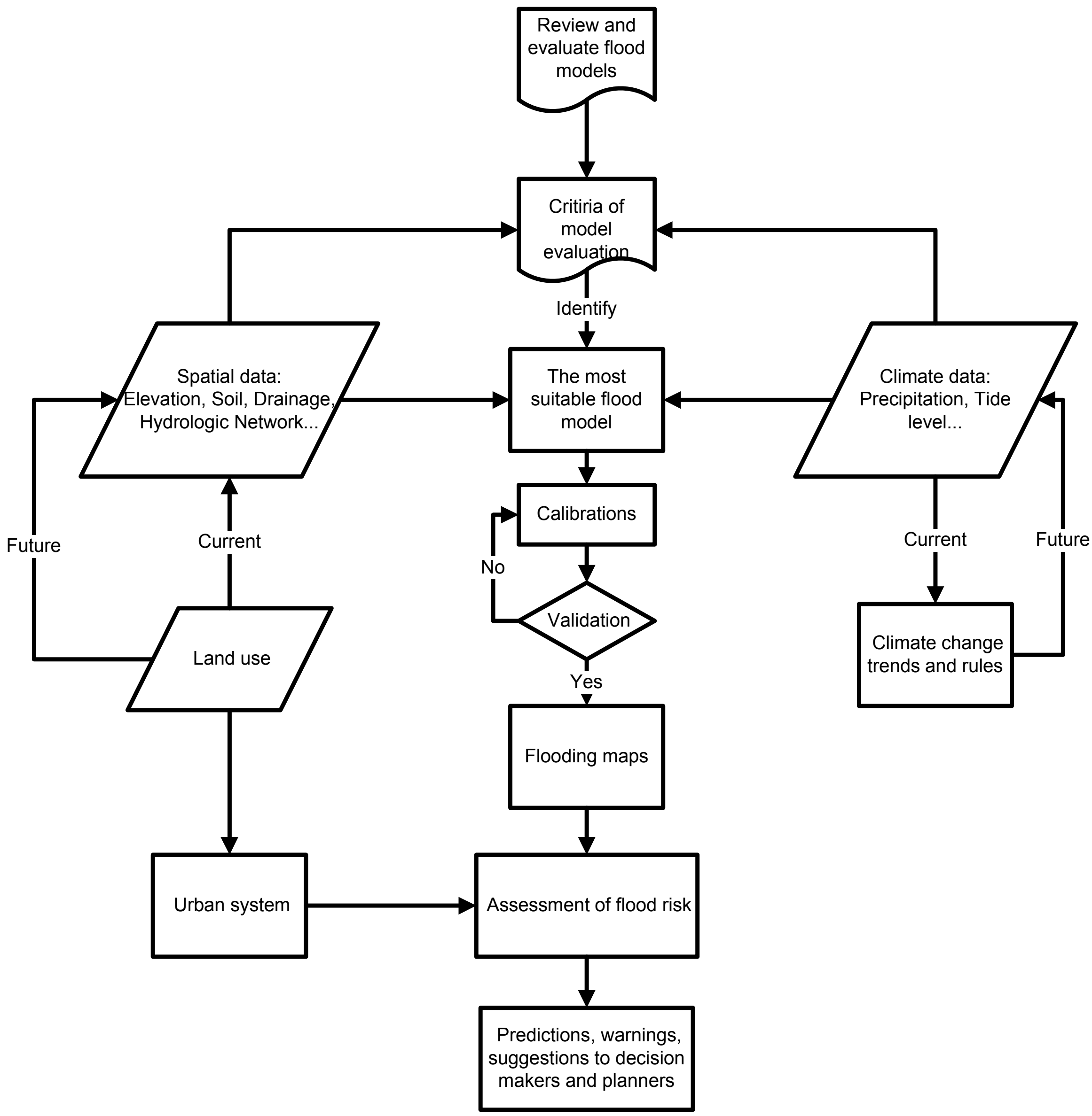


Fig. 1.1: Methodology flowchart

5. Content summary

The thesis is organized into seven chapters to describe whole the tasks carried out of the research. The content of the thesis is performed ordinarily from introduction to the conclusion. These chapters are summarized as the followings.

In the chapter, there is a general introduction about the thesis. The chapter draws a main picture for the thesis. It includes a general review problem in Ho Chi Minh City and then determining objectives of the thesis, methodology, and steps to implement for the investigation and summary content of the chapters in the thesis that the thesis will be conducted.

The chapter 2 shows literature review of the research. The chapter reviews researches relating and applied to this study. It includes GIS and remote sensing, flood models, emission scenarios and climate change and done researches on the flood and climate change in Ho Chi Minh City. The target of the chapter is to evaluate facilities to help the research can be completed and gaps of flood problem in Ho Chi Minh City with climate change conditions.

The chapter 3 the first one describes the real tasks of the research. This chapter presents all stages of the data and database process that includes collecting, editing and errors processing. Besides calculated secondary data are to serve next steps.

The next chapter motivates steps by steps about flood model. It shows choosing the most suitable approach to determine flood areas and its characteristics for the research. And based on the approach, a flood model is built. Further, problems that help to improve the accuracy of result from the model are also mentioned and detailed.

In the chapter 5, chapter 6 and chapter 7 the approaches on flood risk analysis and assessment are described and presented in GIS environment. The steps and theories that are applied of assessment and analysis are mentioned detailed for each of ground objects matching to the research aims such as houses, population, and land use. And results based on theories will be determined. The results are calculated and computed to identify flood risk grades and impact to residents and their properties. Additionally, the discussions of the results are mentioned and explained for the results.

The last chapter is conclusions and recommendations that are collected from chapter 5, chapter 6 and chapter 7. This chapter also mentions suggestions to the stakeholder in the study area such as decision makers, planner and residents living in the flood risk suitable warnings. Moreover, in the chapter, there are assessments that give what the research archives and what the research should be conducted further in the future.

Chapter 2. Literature Review

1. Study area

Study area is located at Ho Chi Minh City center. In the area there are many typical features for Ho Chi Minh City specially and that for urban areas in Viet Nam generally. The characteristics of the study area are described in the next sections (HCMCPC, 2010; HCMCPC, 2011).

Geography: Ho Chi Minh City is located from 10°10'-10°38' north and 106°2'-106°54' east (HCMCPC, 2011). Moreover, Ho Chi Minh City touch with South China Sea so that the city has conditions that are sensitive with the climate change especially sea level rise in the future.

Topography: the study area is located in Ho Chi Minh City which belongs to a transitional region between the southeastern and Mekong Delta regions. The general topography is that Ho Chi Minh City terrain gets lower from north to south and from east to west. So the study are has the medium-height terrain lies in the middle of the city, encompassing most old residential areas.

The area's height is 5-10 meters in Vietnamese vertical reference system that is chosen mean sea level at Hon Dau, Hai Phong for the level zero. The height of the area does not have suddenly change except the areas of a river and canals. The trend of height increases slowly from east to west and from north to south. Moreover there are more than 72.3% areas of the whole urban area of Ho Chi Minh City is below 2 m in Vietnamese vertical reference system (Storch et al., 2009).

Ecology: The ecology of the study area is classified into basic types: the area of trees with some parks, the area of river and canals with water surface, and the other one with resident region with most small and low houses.

Climate: the study area is located in Ho Chi Minh City so it also has climate as Ho Chi Minh City. The city lies in the tropical climate region near the equator. Like southern provinces, it has a high temperature all the year and two distinct seasons, the dry and the rainy. The rainy season lasts from May to November and the dry season from

December to April. According to records of the meteorological observatory at Tan Son Nhat airport, the city's climate has the following features: rich radiation, high rainfall, humidity averages, around 79.5% per year (HCMCPC, 2010).

2. Geographic information system (GIS)

As the name of the GIS, geographic information system, the nature of GIS technology is a combination of processing power to solve problems relating to spatial and non spatial data processing. Therefore, GIS can solve almost applications and simulate spatial phenomena. Consequently nowadays many applications of many other disciplines and fields apply GIS as a environment to integrate and develop their tools so that the applications will be managed, implemented, stored, computed and displayed much better, more visual, easier analysis and more convenient delivering to end users. Moreover GIS is also an environment to develop spatial decision support systems that is helpful for managers and decision makers who make more precise and effective resolutions.

With that tendency, flood management field also applies GIS to make a basic environment for the development of the tools that serve for simulations, computations, analysis and visual display to users. The tendency is promoted strongly nowadays (Vieux, 2005). The process and generation of flooding in reality is very complex to simulate similarly to the real process so that the establishment of the theory to model this process is actually a simplification to simulate a relatively consistent for each specific situation. It is also the answer why many flood models are built. With the trend of development on an advanced nowadays, requirements about flood models must be made the results more accurate and thus the technologies that are used to support to processes of spatial simulation of flood model software are strong. As a result, the requirements of spatial processing for flood models have been meeting the spatial processing functions of GIS. Additionally, the results of GIS are also easily visualized and interpreted to the end users. Moreover, to extract the reports with formats such as maps and tables is also a strong feature of GIS. All these are reviewed and expressed specifically in the book, The GIS Applications for Water, Wastewater, and Storm water Systems, written by Uzair M. Shamsi in 2005 (Shamsi, 2005). The authors focus on applications related to water in urban areas. The book brought to the readers the specific case studies for characteristic applications on water that help the readers being understood and would be able to apply for the same situation easily. Not only GIS is mentioned but the book also showed the integration of remote sensing into the GIS for applications on water. For an example, high resolution satellite images can be used to update information about the changes large-scale land surface such as land use, or environmental damages can be detected based on satellite imagery after disasters such as floods, earthquakes or tsunamis.

Besides, GIS can be applied to the fields of water related to urban regions as Uzair M. Shamsi written it can also apply to model for applications relating to water in the areas where there are more extend such as basins, delta and catchments…. The applications are considered in the document titled Geographic Information Systems in Water Resources Engineering written by Johnson in 2009. The document has shown the methods and provided GIS applications for most of the problems about water resources at basin level as surface water hydrology, groundwater hydrology, wastewater and storm water, and floodplains.

GIS can not only apply the problems of flooding, a lot of researches and documentation have shown that GIS is also used as a powerful analytical tool in analyzing the risks, damage assessments of natural disasters. These are expressed through the cases of study in book Geospatial Techniques in Urban Disaster Hazard Analysis edited by Showalter and Lu (2010). Documents gathered plenty of applied researches which use geospatial techniques for analyzing, evaluating and managing risk, damage caused by natural disasters. Especially in this document there is a separated section for the representation of GIS applications for sea level rise and flood analysis. This section includes 5 chapters containing chapter 3 and chapter 5 focusing on vulnerability assessments (Maantay, Maroko and Culp, 2010; Pavri, 2010), chapter 4 and chapter 6 focusing on risk analysis and management (Bizimana & Schilling, 2010; Deckers, Kellens, Reyns, Vanneuville and Maeyer, 2010) related to flood analysis and sea level rise. The other chapter, chapter 2, relates to apply GIS for modeling of sea level rising on the world (Usery, Choi and Finn, 2010). As the editors summarized in the text, in the chapter 2, Usery, Choi, and Finn’s use GIS to create global animation of sea level rise. Their research is offered not as a predictive model but to demonstrate a methodology for using GIS data layers to create models, animate data, and provide the basis for more detailed modeling which can lead to improved coastal policy-making.

3. Flood models

Flooding problem is a natural phenomenon occurring in the world for a long time. Flood can be defined on FLOODsite (FC, 2009) as follows: "a temporary covering of land by water outside its normal confines". Because of the severity of the flood affected people's lives flood has been studied for a long time in the world (Aronica, Hankin and Beven, 1998a; Bates & De Roo, 2000; Chow, 1973; Cunge, 1975; Cunge, 2003; Horritt, 2004).

Today, flood models and their theories as well are very popular over the world and continuously upgrade day by day. Currently the world there are many models simulating flooding in the reality. These flood models do not only compute but also they can display the results of visualization on the GIS environment (DHI, 2004; DHI, 2007a).

There are many flood models to determine flood characteristics. Depending on goals, accuracy and available data in the study area of each research, there are a lot of flood models applied in the real (Apel, Aronica, Kreibich and Thieken, 2009; Bates & De Roo, 2000; Sanders, 2007). If separation bases on using hydraulic model in the flood models there are two groups. The first is non used hydraulic model and the second is the used hydraulic model.

The flood models that are non used hydraulic model are not based on computation of water wave motion. For this group, there are two types. The type 1 uses a comparison method that considers differences between elevation of ground surface and water level height. Therefore this method is called planar surface (Horritt & Bates, 2001; Nhat, 2011; Nhat & Loi, 2010; Priestnall, Jaafar and Duncan, 2000). The type 2 is based on a statistical relation – regression between flooded area and discharge of the sub catchment and called statistical approach (Townsend & Foster, 2002). To apply the second one in a new study area, there is an area where similar to the new study area and has relationship between flooded area and discharge. Then in the new study area a SAR image is captured and a combination between SAR and the relationship, the characteristics of flood in the new study area are computed including flooded area, depth and duration. The advantages of the group are simple and low computation cost and not needed advance data. However, the results tend more exaggerated than reality because they do not have lost of energy due to transmission (Dung, 2011).

The flood models used hydraulic models are complicated models to simulate all the processes with water wave motion, conservation of energy and momentum of water. To model the process of a flood, the researchers would analyze the flooding process that consists of many smaller processes, but are merged into two major processes such as hydrological and hydraulic processes. Two processes are built to models called hydrological model and hydraulic model. In each process also includes many delicate processes such as the infiltration, evaporation, transpiration, runoff generation process. These processes are modeled by mathematical equations. The method chosen to solve this equation also makes many differences for results of the flood model (NSWDOC-MHL, 2006). To resolve a lot of the aspects, these processes are simulated by equation system. The equation system contains plenty of unknowns related to position, energy and momentum of the water. And depending on the number of spatial unknowns that the model can solve the flood model is called story cell (Bates & De Roo, 2000; Cunge, 1975; Hunter, 2005; Nien, 1996), one dimensional hydraulic (Chaudhry, 2008; Dac, 2005; DHI, 2004; Hoa, Nhan, Wolanski, Tran and Haruyama, 2007; Horritt & Bates, 2002; Pappenberger, Frodsham, Beven, Romanowicz and Matgen, 2007; Werner, 2004), two dimensional hydraulic (Aronica, Tucciarelli and Nasello, 1998b; Carrivick, 2006; DHI, 2007a; Hervouet, Hubert, Janin, Lepeintre and Peltier, 1994), couple one –two dimensional hydraulic (DHI, 2007b; Dung, 2008; Frank, Ostan, Coccato and Stelling, 2001; Hoa et al., 2007; Vorogushyn, Merz, Lindenschmidt and Apel, 2010) and three dimensional hydraulic (Wilson, Yagci, Rauch and Olsen, 2006). To implement of the flood models the input data is available with the elevation in the river bed or at least cross sections of the rivers and canals. The advantages of the models are really approximate simulations so that the results are computed have more accuracy than the first group. However, the disadvantages are needs of detail input data, resources and high computation cost.

4. Climate change

Climate change is one of hot problems in the world nowadays. This change of climate is due to the behaviors of human into the environment so that global warming impacts to the climate and weather of the earth. Depending on the geography and regional natural conditions, different regions of the world are affected at different scales by the climate change. The climate change impact assessments on over the world are presented in the IPCC reports (IPCC, 2001; IPCC, 2007). In the reports IPCC has built the impact on emissions scenarios of the world and based on frame data of IPCC the countries would downscale and calculate the results of climate change at the national level.

For Vietnam, the climate change is a significant and highlight problem because of potential impacts of sea level rise. The reason of that is because Vietnam has a long coastline that is along country from north to south through a lot of areas of the country. According to the studies on the impacts of sea level rise, Vietnam is one of the countries that are seriously affected but especially the low land of delta in southern and northern regions. Realizably those issues Vietnamese state and government have built and developed a national program to study this problem (VNGov., 2008). The national program on climate change and sea level rise is one of important programs which set out the objectives and stages of the preparation for facing impact, risks in Vietnam caused by climate change in the medium and long term.

Based on objectives of the national program on climate change, a lot of researches on climate change are deployed. In 2009, Ministry of Natural Resources and Environment (MONRE) reported results on climate change and sea level rise on regions in Vietnam with interval ten years in the 21st century (MONRE, 2009; Phung & Working Project Team, 2011). And then with frame data of the report, the provincial governments downscales and calculates more detail of result on climate change and sea level rise for their province matching with the real local climate data.

With that direction of the development, Ho Chi Minh City government has been improving the studies related to climate change and sea level rise to serve management and planning. The first thing is to provide the results on climate change and sea level rise in Ho Chi Minh City. The research "Study to build an evaluable model of climate change impacts to natural, human and social economy in Ho Chi Minh City" of Sub Institute of Hydrometeology and Environment of South Viet Nam (Phung & Working Project Team, 2011) had released the results of climate change and sea level rise in Ho Chi Minh City in 2011. That is one of the reference materials for the analysis and calculation of the value weather and rising sea level in this study.

5. Researches related to the thesis

In the recent decades, some researchers began to study the problems concerning to urban flooding in Ho Chi Minh City and shown the causes but they were discrete (Phi, 2007; Phi, 2009; Thang, 2010) or a beginning combination makes sense of the causes for phenomenon of urban flooding in Ho Chi Minh City (Trung, 2009). However, no comprehensive and systematic study on the issue of flooding at the entire city level is made to solve the urban flooding problem here. In the studying of flooding field in Ho Chi Minh City, the researcher, Ho Long Phi has had the researches which are more concentrated for urban flooding problems in Ho Chi Minh City. In climate change research and urban flooding in Ho Chi Minh City (2007), Phi made conclusions about climate change phenomenon is affecting urban flooding problem in Ho Chi Minh City from hydrographic data as shown in table 2.1. From this study Phi showed a tendency to increase the number of heavy rains over time serial. The tendency will make a serious dimension to the problem of urban flooding in Ho Chi Minh in the future.

Tab. 2.1: Increasing the number of heavy rains with volume more than 100m

Period	1952-1961	1962-1971	1972-1981	1982-1991	1992-2002
Counts	0	1	2	2	4

(Source: Phi, 2007)

Additionally, in the research Local Climate Change Research and Urban Flooding in Ho Chi Minh City (2009), Phi pointed out that water level rising in Ho Chi Minh is not only by global climate change but also by local factors as urbanization and land use change which have caused increasing tidal level in the area. The increased rainfall has also exposed a cause of the Ho Chi Minh urban flooding that is poor drainage system in Ho Chi Minh. The status of the drainage system can not be improved from new projects because by problems about setting construction standards for drainage system in Vietnam that have not kept to update with changing climatic conditions in the locality (Thang, 2010).

Besides the researches, a number of organizations have conducted studies to implement urban upgrading projects to address environmental issues and especially, urban flooding is one of them. Currently there are many projects large and small to solve urban flooding problem, but the most important projects are the three followings: Ho Chi Minh City Environmental Sanitation Project – Nhieu Loc Thi Nghe Basin, Tan Hoa Lo Gom Canal Sanitation and Urban Upgrading Project, and Drainage and Pollution Treatment in Tham Luong – Ben Cat – Nuoc Len Canal Project. These projects focus on environmental improvement and urban upgrading in order to reduce the urban flooding status in the three major basins of the Ho Chi Minh. To improve the urban flooding status, the projects have studied to design large sewer systems to enhance storm water drainage for the city. But according to experts evaluations, these projects have not been put into operation, they were outdated because the hydrologic data that had been used as requirements of construction standards for the design were not consistent with and less than real values. Therefore, when these projects will be completed, the problem of urban flooding is still continuing (Phi, 2009).

Tab. 2.2: Sea level rises SLR (cm) relate to SL of period 1980 – 1999

Emission scenarios	**Years**								
	2020	2030	2040	2050	2060	2070	2080	2090	2100
Low (B1)	11	17	23	28	35	42	50	57	65
Medium (B2)	12	17	23	30	37	46	54	64	75
High (A1FI)	12	17	24	33	44	57	71	86	100

(Source: MONRE, 2009)

A key document on climate change in Ho Chi Minh is a report that is released by the Ministry of Natural Resources and Environment. This report is based on a research in the Institute of Hydrometeorology and Environment to construct climate change scenarios that used downscaling approach in the scenarios of global climate change scenarios in the assessment report of the IPCC fourth time in 2007 (IPCC, 2007). In this report, MONRE calculated and delivered values of sea level rising and trends of rainfall variability under climate change scenarios in all regions of Vietnam. Particularly, Ho Chi Minh City data on sea level rising are shown in table 2.2.

The latest the document on the impact of climate change to Ho Chi Minh City is a synthesis study report of Asian Development Bank (ADB) in 2010 (ADB, 2010). This is a study report of a project named Ho Chi Minh City Adaptation to Climate Change. This project is to assess the impact, damage, risk and vulnerability at the large scale on all aspects in Ho Chi Minh City as the economy, society, environment, transportation, infrastructure, agriculture, industry in 2050 under climate change conditions to assist the Ho Chi Minh City People's Committee and its results is to recommend the adaptation policies to help cities sustainable development in the future. The project had focused largely on vulnerability assessment, impact of climate change in 2050 based on scenarios that were integrated of sea level rising, precipitation increasing in the status of typhoons. To build inundated areas, a hydraulic model HydroGIS (Hoanh, Phong, Trung, Dung, Hien, Ngoc and Tuong, 2012; Nhan, Hoa, Cong and Diep, 2009; Thai, 2011) had been used and then assessing impact, damage, risk and vulnerability to the areas in Ho Chi Minh City is based on the results of the model. Generally this is a comprehensive study project for the projected impacts of climate change to Ho Chi Minh City in 2050. However, with using HydroGIS model to identify flooding areas was not appropriate and accurate. That is because HydroGIS model built based on river flooding. Moreover, HydroGIS model can not simulate the street elevation and irrigation system for controlling flow water from rivers. Thus applying this model will not correct for flooding phenomenon in urban areas such as Ho Chi Minh City. And a gap of the study that is the results had not considered the impact of land subsidence flooding in Ho Chi Minh City (ADB, 2009a; ADB, 2009b; WB, 2010). The next one is procedure of the model implementation duration that there was not the calibration process for parameters of the model before the model was applied to create scenarios for future so that the results are not highly reliable.

To be able to say up to now, the studies related to urban flooding in Ho Chi Minh City are also discrete. The studies to current urban flooding problem have not been completed or perfect, the studies toward the future there is the ADB project that is fairly complete however the project focuses only on analyzing the impact of climate change scenarios to urban in Ho Chi Minh City. It has not been implemented systematic study on the existing flooding situation. Additionally, the tool used for the study has not been scientific because the study only tries to run the model to reap outputs without regard to the appropriate context of performance of the model.

Chapter 3. Data and database

1. Collecting data

This is big problem for any researches in Vietnam because the regulations of publishing and updating data are very strict and not consistent. The data for the study can be divided into the following groups: climate data, data for flood model and data for assessments. The data groups are described in the following paragraphs with data information and evaluation in the context of the research requirements.

Climate data include tide level, rainfall and temperature for a reference time period of calculated climate change. The reference time period shown by the IPCC and Vietnam is from 1980 to 1999 (IPCC, 2007; MONRE, 2009). The data for the reference time period are collected and almost this serial data are not missed. Moreover to calculate tide level, precipitation of rain and temperature in the future time, the scenarios of sea level rise in Ho Chi Minh City, rainfall and temperature changes are collected.

Data for a flood model include data for implementation and data for calibration. Data for implementation need a perfect terrain or river-canal network and their cross sections, drainage system and land use in the study area. The research collected terrestrial elevation points, drainage system, cross sections of Nhieu Loc-Thi Nghe canal sub catchment and land use of whole the city. This data group is missed almost the cross sections for river – canal network besides the observed data serves for calibration and verification of flood model.

Data for assessments the research has collected data of urban system including: the latest administration boundary at the community level, population data in 2009, traffic system and build up footprint in 2006.

Results of data collection are shown in table 3.1. These data are available in many formats, consequently editing task that change to a standard GIS data consumes many time. Basically there are three types of collected main data: GIS data, tables and text.

GIS format includes the following data: elevation points excluding river and canal network, river-canal network, the latest administration boundary at the community level, traffic system, buildup footprint and land use. Although these data in GIS formats, but there is still a lot of errors of spatial relationship that needs to edit and correct.

Tabular data includes: population, climate data, and climate change scenarios. All this data should be transferred to GIS format or associated with spatial objects in GIS respectively. Besides they need to be checked the accuracy before being used for research.

Text data includes: drainage system and cross sections of Nhieu Loc Thi Nghe sub catchment. The conversion and editing data in GIS format takes a lot of time. Currently data is being prioritized for editing and progress. Together with the editing, checking and correcting is carried out.

2. Editing and correcting data

In GIS, there are two types of information for each object. The first is the spatial information related to the geometry and position of the object. The second is information related to nonspatial or in the other word called object attributes. The editing data is mostly issues concern in terms of the geometry and spatial problems of the object that are emended and corrected exactly in geographical location. The object attributes are almost unchanged because they have been determined by management agencies in Vietnam.

The spatial data have many types of error that are based on the geometry features with polygon, line or point. The errors occur in the polygon data are the overlays and the gaps between objects in the same feature class due to defect in snapping between the vertices of two adjacent objects. The errors appearing in the linear data are primarily caused from missing of the digitization processing such as snapping of adjacent features in the feature class. The errors include overlap and self overlap, pseudo nodes and dangles. Additionally, the data also need to check the lines of the data must be within Ho Chi Minh City. And the last geometry type of the data is point. With the point in the research there are elevation data and out-inlet gates. In these data, the elevation points need to check because there are some residual points between terrain points and features points such as misunderstood points in roads, buildings, bench mark.

Method of identifying errors is to check problems about geometry, location and the spatial relationships between objects in the same feature class or between data layers with each other that are based on regulations called topology rules. After identifying the errors, method for correcting errors depends on the types of errors. If the errors show wrong locations, the features in the data will be corrected to right locations based on the satellite image. With the features are misunderstood, they will be deleted.

3. Population data

Population data includes information at the time points that the research interests for assessment at the current and future scenarios. For the current scenario, the population data is collected at the commune level that is surveyed and inventory whole the country on the first April 2009.

Data are collected and used in the research are shown in the table 3.1. In the table the columns describe the information of the data including data name, published date and data source. Published date is year when the data is official delivered popularly to third parties which need to use the data. The data source is legal organizations which can issue for the other organizations for using.

4. Analyzing and calculating climate data

4.1. Identifying climate change trend and rules

This task is being considered as the scenarios of climate change. Therefore, this action is part of the collected data. The data on climate change trend and rules are presented as table 3.2 and table 3.3. Table 3.2 shows sea level rising in Vietnam and Ho Chi Minh City for 21st century with interval of 10 years (Phung & Working Project Team, 2011). The sea level rising is compared with sea level of referent time 1980-1999. Additionally, to calculate the tide level in the future time when there is climate change needs to identify value of interval average tide level increment. The values are shown in the table 3.3 (Phung & Working Project Team, 2011).

Tab. 3.1: The summary of data to use in the research

Data Name	**Format**	**Coordi-nate**	**Object Type**	**No. of objects**	**Attribu-tes**	**Year**	**Source**
Elevation Points	Geo-database	HCMC -VN2000	Point	529799	Eleva-tion	2004	Mr. Phan Nguyen Viet Geomatic Center - VNUHCM
Rivers - Canals	Geo-database	HCMC -VN2000	Poly-gon	1761	Name, Area	2006	Mr. Phan Nguyen Viet Geomatic Center - VNUHCM
Buildings	Geo-databse	HCMC -VN2000	Poly-gon	787860	Storey number , Area,	2006	Mr. Phan Nguyen Viet Geomatic Center - VNUHCM
Line Roads	Geo-database	HCMC -VN2000	Line	47721	Length	2006	Mr. Phan Nguyen Viet Geomatic Center - VNUHCM
Polygon Roads	Geo-database	HCMC -VN2000	Poly-gon	20473	Name, Area	2006	Mr. Phan Nguyen Viet Geomatic Center - VNUHCM
Admini-stration Boundary	Geo-database	HCMC -VN2000	Poly-gon	322	Name, Area, Populat ion	2006	Mr. Phan Nguyen Viet Geomatic Center - VNUHCM
Dike system	Shapefile	HCMC -VN2000	Line	569	Length, Height	2012	Mr. Nguyen Hong Dung - BFCI-DARD
Out-Inlets gates	Shapefile	HCMC -VN2000	Point	521		2012	Mr. Nguyen Hong Dung - BFCI-DARD
Land Use	Shapefile	UTM48 -WGS84	Poly-gon	16319	UST Code, Area	2011	BMBF-Megacity Research Project: TP.Ho Chi Minh, Vietnam - Adaptation To Climate Change
Tide level	Text	N/A	N/A	(*)	N/A	1980-1999	Mr. Ho Long Phi - SCFC
Popula-tion	Text	N/A	N/A	(**)	N/A	2009	HCMCSO

(*) Tide levels was recorded at the Phu An Station in the Sai Gon River in hourly

(**) Population data is enclosed with each of the communes

Tab. 3.2: Sea level rising SLR (cm) relate to SL of period 1980 - 1999 in Ho Chi Minh City

Emission scenarios	**Years**								
	2020	2030	2040	2050	2060	2070	2080	2090	2100
Low (B1)	13	18	23	28	34	39	44	49	54
Medium (B2)	15	21	27	31	41	48	56	64	72
High (A1FI)	15	22	30	38	47	57	68	80	93

(Source: Phung & Working Project Team, 2011)

Tab. 3.3: Interval average tide level increment (cm) at the forecast times in Ho Chi Minh City

Interval (year)	10	20	50	100
dhi (cm)	14	19	25	30

(Source: Phung & Working Project Team, 2011)

4.2. Identifying the future time point to assess flood risk

The identifying the future time point to assess flood risk needs to be chosen to match the planning data. At the time point the planning data can be evaluated flood risk to types of land use when climate change. Additionally, the time point should be predictable and suitable accuracy. Because if the time point is close from the present time, purpose of forecast is not too high but if the time point is too far from the present time, the accuracy is not high and the fact that the planning at that time has been modified. Moreover, the forecast data of sea level rise scenarios are updated for each tidal cycle of 20 years.

Differently to ADB research in 2009 (ADB, 2009a; ADB, 2009b) the future time point to assess is based on the spatial planning map for Ho Chi Minh City by 2025 vision 2050 so that ADB decided to choose 2050 for assessment. However, as the above considerations and analyses, this research selects year 2030 for the evaluation and comparison flood risks.

4.3. Identifying peaks and their appearance number of the tide level

Identifying and calculating tide level peaks in the study area daily are important. Additionally, the peaks are shown the tide heights that impact flooded areas it also address the frequency of the flood can appear for the time. Based on those the flood risk can be explored.

In Ho Chi Minh City, the tidal regime is of semi-diurnal tide so that tidal peak number each day is usually two times. Therefore there are a difference amount of flood between flooding by max level and peak of tide per day and calculating peak number of tide per day is essential for flood risk assessment.

To identify and calculate the tidal daily peaks, the research carry out analyze chain data of tide at the Phu An measurement station on Sai Gon River with time interval is hourly. The method to define tidal peak is comparison value of tide level at a time point with before and after adjacent values (Mudelsee, 2010). If the value of tide level is more than before and after adjacent values, the value is peak and otherwise the value is not. The chain data is analyzed continuously time by time for whole the period of time (1980-1999).

The next step is computation of number of the tide peaks in the value chain. Method of determining number of the appearance of the tide peaks is based on the set of the tide peaks. Then a processing of count from the set of tide peaks will be done to determine a number of appearances for each of tide peak value.

To process the tasks, the research develops a program in the Freemat programming language (Sourceforge.net, 2012) to analyze and identify the tide peaks. The result of the tide peak and frequency is shown the table 3.4.

4.4. Calculating climate data at the future time point

Calculating tide level at a station under climate change at the future time point is based on three elements (as shown in equation 3.1): high tide at the reference time, rising sea level at the time point and interval average tide level increment at that time point (dh_i). To determine the value of dh_i is complicated because this task needs support of many software and data to analyze the harmonic astronomical cycles. However, there is a research with title “Study to build an evaluable model of climate change impacts to natural, human and social economy in Ho Chi Minh City" (Phung & Working Project Team, 2011) that determined the experimental values of dh_i in Ho Chi Minh City, as shown in table 3.3.

$$H_t = H_c + dh_{ct} + dh_i \qquad \text{Equ. 3.1}$$

Where:

H_t: tide level at the forecast time
H_c: tide level in the referenced time
dh_{ct}: sea level rising at the forecast time
dh_i: interval average tide level increment at the forecast time

Tab. 3.4: Tide height and frequency in 2030 with daily tide level peaks

	Scenarios					Scenarios					Scenarios			
Value	B1 (cm)	B2 (cm)	A1FI (cm)	Fre	Value	B1 (cm)	B2 (cm)	A1FI (cm)	Fre	Value	B1 (cm)	B2 (cm)	A1FI (cm)	Fre
101	140	143	144	190	114	153	156	157	84	127	166	169	170	19
102	141	144	145	154	115	154	157	158	87	128	167	170	171	17
103	142	145	146	185	116	155	158	159	78	129	168	171	172	10
104	143	146	147	178	117	156	159	160	72	130	169	172	173	13
105	144	147	148	205	118	157	160	161	52	131	170	173	174	10
106	145	148	149	180	119	158	161	162	53	132	171	174	175	7
107	146	149	150	187	120	159	162	163	44	133	172	175	176	6
108	147	150	151	151	121	160	163	164	45	134	173	176	177	4
109	148	151	152	153	122	161	164	165	45	135	174	177	178	5
110	149	152	153	125	123	162	165	166	36	136	175	178	179	1
111	150	153	154	125	124	163	166	167	38	137	176	179	180	1
112	151	154	155	109	125	164	167	168	28	139	178	181	182	1
113	152	155	156	106	126	165	168	169	23	142	**181**	**184**	**185**	1

The data in the table 3.4 shows that the peaks of tide level in 2030 on SLR of the emission scenarios in Ho Chi Minh City are 181cm with B1, 184cm with B2 and 185cm with A1FI. They are not so much different. Table 3.4 is a calculation of tide height and frequency in 2030 with daily tide level peaks.

Tab. 3.5: Frequencies of daily sea level peaks over 1.5m in three emission scenarios and average times per month at year 2030

Scenarios	**AF/month**
B1	5
B2	7
A1FI	8

In the table 3.5 the frequency of tide peaks is more than current average tide level 1.5m on the scenarios is very much. The result of the frequency is shown in the table 3.5 This means with the current flooded areas at the tide level 1.5m will be inundated more than from 5 to 8 times per month matching to the scenarios. This information is a warning to the residents who are living there because of flood impact of their life activities.

Chapter 4. Building Flood Model and Flooding Maps

1. Selecting a suitable flood model for the research

1.1. Build criteria of selection

The construction of evaluation criteria is to be able to choose the most appropriate model for flooding context and data in Ho Chi Minh City of this study. These criteria are an attachment between goals of the study, the flooding context and the available data in the Ho Chi Minh City. Therefore the criteria will be integrated and expressed the following requirements:

- Research outcomes: Outcomes of the model must be calculated for whole of the city.
- Available data on flooding study in Ho Chi Minh City: At least the flood model determines the flooded areas with sea level rise.
- Abilities of flood model software: to be able to determine the flooded area, flooding depth, flooding duration, and flooding frequency.
- Complexity of the model software on the operation and learning it: the model software is the most simple as possible.
- Cost of software: the least fee is priority.

1.2. Analysis and selection the most suitable flood model

As mentioned in the flood model review of chapter 2, the flood models are classified two groups: non used hydraulic model (Horritt & Bates, 2001; Nhat, 2011; Nhat & Loi, 2010; Priestnall et al., 2000; Townsend & Foster, 2002) and used hydraulic model (Aronica et al., 1998b; Chaudhry, 2008; Cunge, 1975; Dac, 2005; DHI, 2007a; Dung, 2008; Nhan et al., 2009; Nien, 1996; NSWDOC-MHL, 2006; Vorogushyn et al., 2010; Wilson et al., 2006). Base on the criteria of selection a suitable flood model, the research outcome covers whole of the Ho Chi Minh City but availability of input data for hydraulic model is not completed so that flood models of the second group is not suitable.

In the first group, there are two approaches for build flood model that are the planar surface and statistical. The second approach requires a similar study area to Ho Chi Minh City with relationship between flooded area and discharge but in the reality there is not any region on over the world be able to satisfy these conditions. Therefore the first approach called planar surface is the most suitable flood model to implement for the research.

The planar surface approach has many advantages when it is implemented GIS environment. This reasons due to GIS functions:

- Very fast and accurate for modeling terrain surface with digital terrain model (DTM)
- Interpolate values for the others values accurately and efficiently
- Simulate ground features more detailed so that the terrain surface is the most approximate with reality
- Tide records, one of input data are integrated GIS easily
- Computing the flood characteristics such as depth, duration and frequency conveniently
- Results from the approach are suitable for flood risk assessments of the next tasks
- And if this approach is selected, there is not more the cost for software

2. Interpolating roads elevations

Interpolating roads elevations is based on the discrete elevation points inside of the roads (Nhat, 2012). That is to make the roads with continuous along road height so that the roads can be barriers to protect low land preventing flooding. Basically the process is carried out based on the elevation interpolation of along a road with known height information of the start and end points of a line (ESRI, 2011). From that principle, the road elevation interpolation of polygons will be converted to that of interpolation of line and then use interpolated road line to build a terrain model in TIN format (Abdul-Rahman & Pilouk, 2008; Gold, 2005; Wilson & Gallant, 2000; Zhou, Lees and Tang, 2008) before all the points of each the road polygons are computed. Steps of the procedure are as shown in figure 4.1.

The first step is selecting elevation of the points inside road polygons then converting road polygons to road center polylines. It is accuracy to split lines, each point is used only once for the nearest road with it. Consequently, the discrete elevation points must be snapped to road center polylines before split is carried out. The distance for using in the snap should be the maximum width of the roads. In the study case the maximum width is 50m.

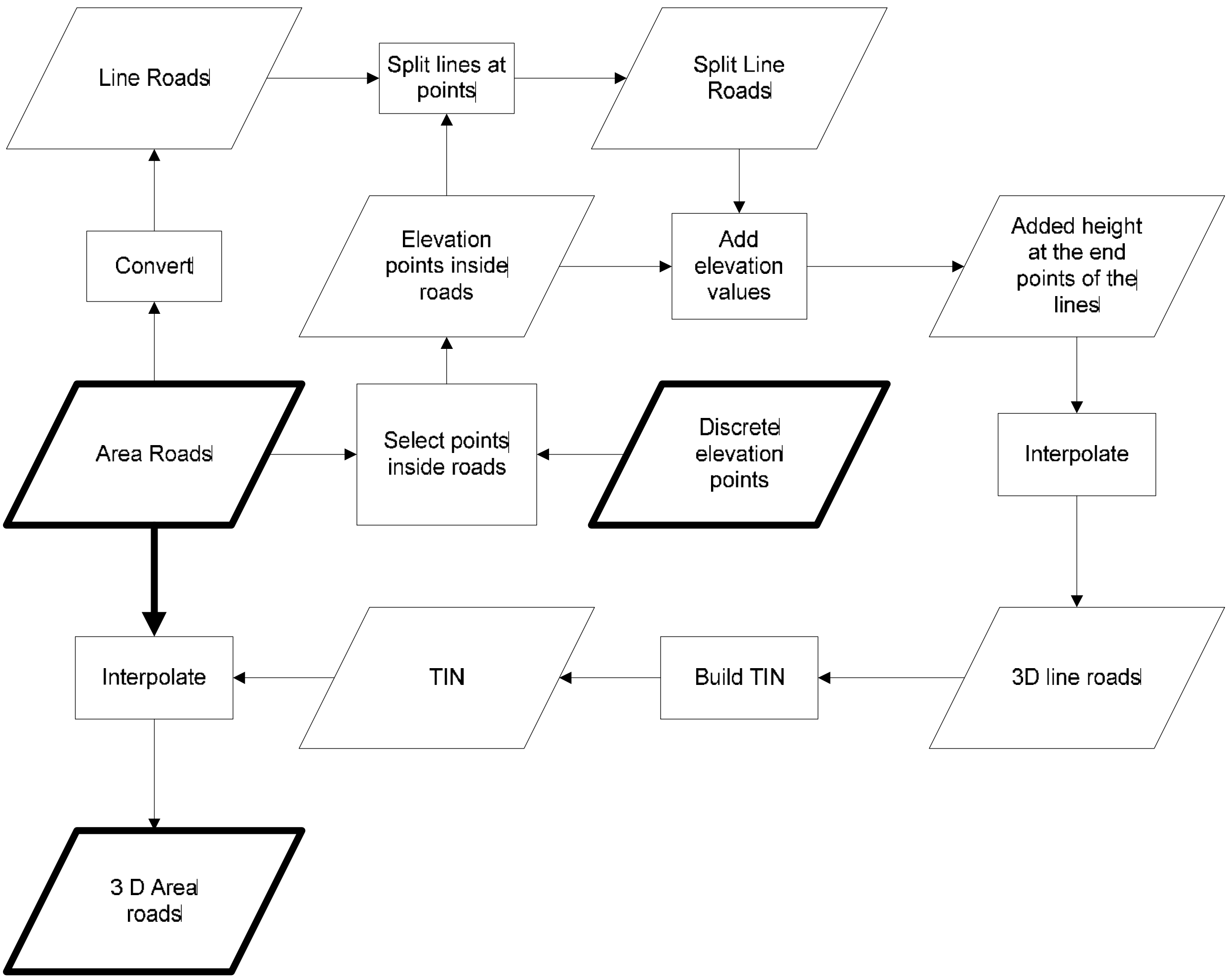


Fig. 4.1: Flow chart of the interpolation procedure

After split has done, start and end points of the road center polylines will be extracted and then assigned height values to them. There are two types of the start and end points of the road center polylines. The first type is the coincided points with discrete elevation points at the split position. The second one is the start and end points that existed before splitting. With the first case, their height values are same as the discrete elevation points at the split positions.

$$z_k = \frac{\sum_{i=1}^{n} \frac{z_i}{l_i}}{\sum_{i=1}^{n} \frac{1}{l_i}} \qquad \text{Equ. 4. 1}$$

Where:

n: number of the road lines connected to the end point k

z_k: elevation of the end point k

z_i: elevation of the road line i

l_i: the length of the road line i

With the second, one more step must be done that is elevation interpolation for them from the lines assigned elevation and connected the start and end points that need elevation information. The elevation interpolation of these points will be calculated considerably with the inversion distance weight (Gold, 2005; Longley, Goodchild and Maguire, 2005; Sheimy, Valeo and Habib, 2005) based on length of the road lines connected with the points. If the end point called k is common of n road lines and each of the road lines has length l_i (i = 1…n). The elevation of the end point z_k is calculated as shown in the equation 4.1.

The next step is attaching height values from the start and end points to attributes of the each of road center polylines. And after the each of the road center polylines contains height values, the height interpolation procedure for all vertices of the polylines is conducted. The method to do this task is linear interpolation (Loi, Dinh and Nhat, 2008; Longley et al., 2005) with distance weight to the start and end points of the polylines. Result of the interpolation is road center polylines in three dimensions (3D).

And then is using the road center polylines 3D combine with the discrete elevation points to build a TIN (Abdul-Rahman & Pilouk, 2008; Zhou et al., 2008) for interpolating the road polygons. In this step the interpolation method is the nearest neighbor with sample distance 25m. That this will make the heterogeneity of the vertexes of the road center polylines and road polygons will be reduced and increase the high accuracy of the road polygons. Final step will get the road polygons in 3D.

3. Buildings height interpolation

Nowadays, to determine height of the ground objects there are approaches to conduct this task. However, these approaches require a lot of resources of technology and cost. With the latest technology the first one that should be mentioned for getting elevation of ground objects with high accuracy need to be listed is LIDAR (Cobby, Mason and Davenport, 2001; El-Omari & Moselhi, 2008; Madhavan, Wang, Tanahashi, Hirayu, Niwa, Yamamoto, Tachibana and Sasagawa, 2006; Oude-Elberink & Vosselman, 2011; Pu, Rutzinger, Vosselman and S., 2011; Yang, Fang and Li, 2013; Yoon, Sagong, Lee and Lee, 2009). And one more technology is applied common almost the countries for producing cartography is stereo aerial photo (Ahmadabadian, Robson, Boehm, Shortis, Wenzel and Fritsch, 2013; Altmaier & Kany, 2002; Baltsavias, 1999; Barnea & Filin, 2013; Gabet, Giraudon and Renouard, 1997; Pollefeys, Koch, Vergauwen and Van-Gool, 2000; Zebedin, Klaus, Gruber-Geymayer and Karner, 2006). The final, oldest and best accuracy is geodesy (Wahr, 1996). And some latest decades, a new technology that complements for geodesy for surveying the ground locations of the objects is GPS (El-Rabbany, 2002; Grewal, Weill and Andrews, 2007; Samama, 2008). With the technologies the vertical information of the ground objects is collected to the accuracy depended on application requirements. However because of limitation of the resources, this research can not use these approaches to get the vertical information of the ground objects. To apply only available resources, the research develops and builds a new approach to derive the vertical information that is based on spatial relationship of elevation between ground objects to each other.

To determine an interpolation method to derive base height of the buildings, the first task should be highly considered that is the building objects relationship with other ground objects that have already height information. To do the task, the analysis of building characteristic of construction in the study area is applied. Here there are able to divide two types of building. The first is built in clusters and the second is discrete. Most of the cluster buildings are usually constructed in urban zone with roads in front of them. About the discrete buildings are usually located in rural areas and constructed on the productive land.

For cluster buildings, their characteristic of base elevation is related to base height of roads in front of the buildings. In these buildings, there are two types of spatial relationship with the roads. The first type touches to a road and the second does not. With the first type, base elevation of the buildings is normally higher a difference than the road surface height. The value of the difference does not equal to whole the buildings but an average different value is chosen for this research based on the construction forum in Ho Chi Minh City (SF, 2007). The average different value is 30 cm above road surface height. The second type is not touched with the roads but they are touched with buildings of the first type. Therefore their base elevation will be interpolated from buildings elevation of the first type. The process is propagated gradually with increasing distant values from buildings that is the closest the roads to further ones. The values of searching radius to define spatial relationship between buildings had base elevation and buildings not had base elevation are also changed gradually from low to high that appears because is not all buildings touched with another. The process is loops to add the base elevation of buildings and the highest searching radius threshold is 20m. The threshold is an average road width of the new developing urban clusters but there have not been updated road data. The loops will be implemented the first time with searching radius is 0m and then there is not any building in the searching radius then radius distance will be increased to 1m. And the process will be iterated similarly to searching radius reaches to 20m.

With the discrete buildings in the rural area, the building foundation height is interpolated ground height and plus a difference between building ground floor and land surface. In the Ho Chi Minh City, the buildings in the rural area are usually constructed higher natural ground surface around 0.4m – 1m (SF, 2007).

In general, building foundation height formula is shown in the equation 4.2

$$Z_h = Z_{ref} + dZ \qquad \text{Equ. 4.2}$$

In that Z_{ref}: the referent height. In the cluster buildings case, Z_{ref} is the height of the closest street, and the discrete one Z_{ref} is ground elevation at the place where the building is located.

dZ: height difference between building ground floor and referent height Z_{ref}. In the research, dZ value of the cluster buildings is 0,3m and that of discrete buildings in the rural area is 0,7m. The values of dZ are based on practical experiences of the civil engineers.

4. Classifying the rivers causing flood

The approach of the flood model is connection the land where is lower than interested tide level with the river, canal and urban drainage system. However, at the current in Ho Chi Minh City there is a lot of available irrigation and dike systems to server providing water for fields and protect the low land against the high tide. The systems contain many embankments and out-inlet gates to control water quantity from provide sources such as rivers and canals. Therefore, with river and canal system, the research must classify two types of rivers and canals: type 1is able to cause flood and the type 2 is not able to cause flood.

To classify rivers and canals, the first step is update the dyke system with dykes, levees and gate. And then the research will separate the rivers cause flood and not cause flood. The rivers and canals causing flood are rivers and canals that do not exist barriers by gates and they can drive water from water sources to the low land and make flood. Therefore the land below the tide level and touch with the rivers causing flood is inundated.

Otherwise, the rivers and canals uncausing flood are rivers and canals that are existing barriers by gates at their out-inlet. Moreover, rivers and canals which are supplied water by the rivers and canals uncausing flood are also considered as those of uncausing flood.

5. Building the flooding model

Method to determine flooded areas of the research is based on the vent principle. That means water will flow to the lowland areas when these areas are touched to the water from the ocean through connection systems like rivers, canal or drainage. The entire flooded area modeling for the research is described in figure 4.2.

Firstly, a terrain surface needs to be built. The surface represents terrain elevation of interest area. In order to represent the terrain surface for the Earth's surface, GIS technology has made two types: Triangle Irregular Network which is also known as TIN (Longley et al., 2005) and raster format which is a grid and commonly called digital elevation model DEM (Longley et al., 2005). The terrain surface is represented raster format having the advantage that is easier to analyze spatial processing due to simplicity in its data structure. However the raster can not express a terrain surface which has complex arrangement of the ground objects and extreme changes of elevation in the areas where there are artificial objects such as dykes, streets, banks of rivers. In addition to a raster is built from interpolation algorithms that are always existing errors whose significant degree depends on the selected resolution and topographic characteristics (Booij, 2005). Because the accuracy of the raster depends on the resolution and the topographic characteristics, terrain objects smaller than the size of a pixel in the raster will not be shown and the different topographic characteristics will be changed in different height residuals. That in fact the flooding problem, there are many ground features works to prevent flooding as dykes, streets but their small size makes it difficult to achieve a representation on the raster. Contrary to the raster structure TIN is created by more complex algorithm and defined data structure so that it consumes more time to spatial analysis but TIN has strengths that can express mutational changes of terrain and objects with different sizes on the surface that can be represented if there is their information of elevation or vertical values. Another strength is that it will not have the interpolation error thus if the input data have high accuracy, the model will have good accuracy (Abdul-Rahman & Pilouk, 2008).

The goal of the terrain surface in the research is to identify the positions of lowland where has the risk of potential flooding (Deckers et al., 2010; Usery et al., 2010). The identification of these positions needs a terrain surface that models more accurate the real terrain surface as possible so that this will also help the high accuracy of the research results. With these requirements, the research have used TIN structure to represent terrain surface for the study area where requires to identify areas of potential flooding. The terrain surface in TIN format of this research is called DTM with integration of the ground objects

In TIN structure there are the components to build it. The components include points, lines and polygons. The points in TIN structure are elevation points that use to create nodes in triangles. The lines in TIN include edges of the triangles which can be created from connection between nodes or can be from the lines or polylines known as breaklines that are considered to represent a sudden change or physical boundaries or nonphysical expressed by user needs. The polygons include the main triangles which are created from the nodes. The other special polygons are to represent topographic characteristics that are irregular and extreme change of altitudes at the ground objects such as lakes, ponds, dykes… to represent accurately the terrain surface and more details. Principle to build TIN surface when there are existing breaklines is nodes, vertexes on the breaklines to be integrated to build irregular triangles following a principle that is circumscribed circle of set three any points is not always contained any other point. The breaklines and edges of the polygons showing special ground features including streets, buildings and dykes that enclose information of elevation will always be the edges of the irregular triangles in TIN structure.

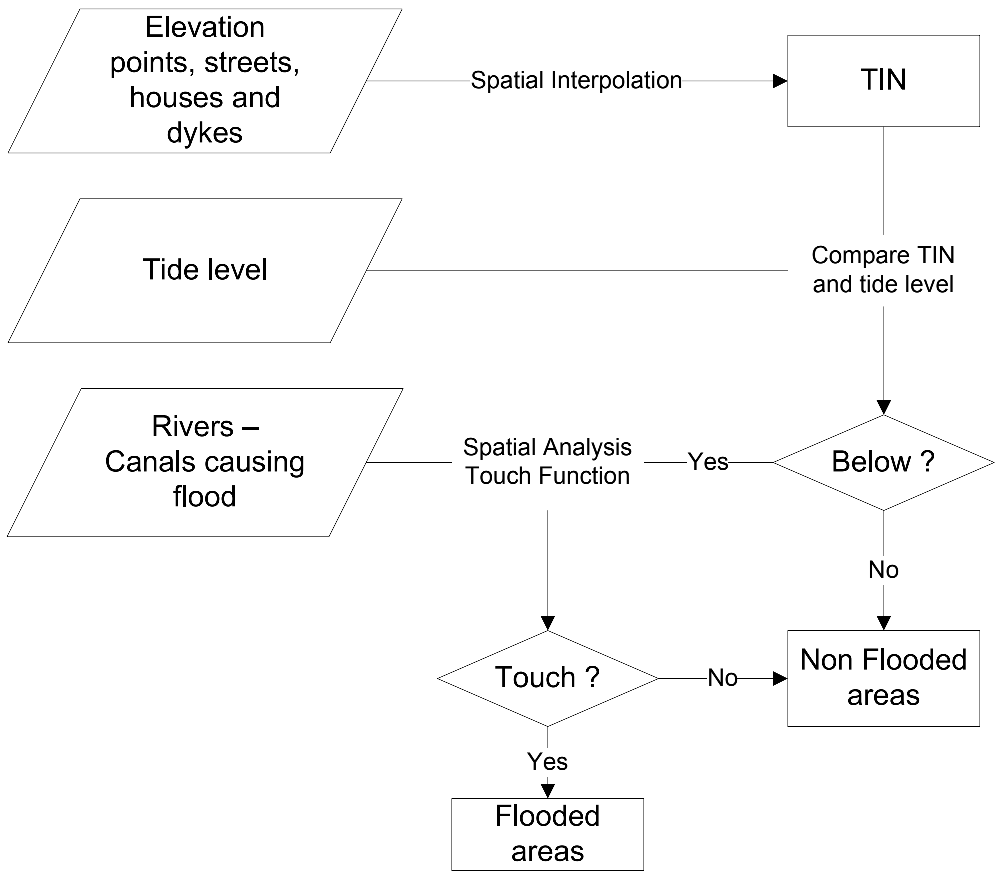


Fig. 4.2: Principle of flooded area model

In the research, the nodes are elevation points. And the lines and polygons that are ground features creating extreme changes of vertical values which impact to flooding prone areas include river canal network, lakes and dykes.

Based on the sea level, positions whose elevation is lower than sea level will be theoretic potential flooding positions. Method to identify a position being a theoretic potential flooding position is a comparison between elevation of the position and sea level altitude. Integrating the theoretic adjacent potential flooding positions will make theoretic potential flooding areas. From the theoretic potential flooding areas, a polygon layer will be created. However, all positions where are lower than sea level are not flooding areas because below sea level is necessary condition but is not sufficient condition for a position becomes real potential flooding. To be a real potential flooding position it must touch to connection system of sea water called connection system layer such as rivers, canals, drainage system connected to canals or rivers that is also the sufficient condition for a theoretic potential flooding position to be real one. In order to identify which polygon of the theoretic potential flooding areas, the research applies spatial analysis tool with function touch between the theoretic potential flooding area layer and connection system layers. If the polygons of theoretic potential flooding area layer touch with the connection system layer, those polygons are real potential flooding areas.

Besides purpose to define the flooded areas, the flow chart is main procedure for producing other flood characteristics. Because of different elevation of the terrain, flooded areas at different tide levels are not the same. Therefore, the flow chart is run for each of loops in the computing and identifying procedure of the flood characteristics at each of interested tide levels.

Normally a flood has some characteristics that are used to assess risks of the flood including depth, area, duration, flow speed and frequency. In the research, the maps are flooded area, flooding depth, duration and frequency. The flood flow speed is not able to define because flood model applied has not the function and additionally flooding in Ho Chi Minh City is caused by tide level so that the flow speed is very weak. These maps have a relationship with each other. With flooding is caused by rising tide, the tide level has constraint with three characteristics: flooded areas, depth and duration. The tide level is higher the flooded areas is larger, the flooding depth is deeper and flooding duration is longer. The terrain elevation is not only correlation with above three characteristics but it also does with the frequency if consideration of each position on the terrain. The terrain elevation is lower, the frequency is higher. These combinations will expose vulnerability and risk of flood.

6. Results of flood model and flooding maps

6.1. Digital Terrain model and drainage system

In general, terrain in Ho Chi Minh City is flat and does not change very much. Almost elevation of the city is below 2.0m referred to Vietnamese vertical coordinate system. There are some zones that have some hills and the old city center located in west northern and east northern regions is above 2.0m. These zones are not connected continuously and they are separated by canal and river sub catchments where low lands are.

The city dyke system is developed much more in the recent years to reduce flood impact on manufactory and living activities of residents caused by high tides. The system includes main dykes along main rivers such as Sai Gon River and canals. They are connected to the dykes of irrigation in the fields to protect agricultural lands in the west and west northern regions. The dyke system builds protection constructions for the residential and manufactory areas. Moreover, at the out-inlet of the canals, there are a lot of gates to control water flow from rivers into the canals so that tide level in the canals is not too high for making a flood. In the figure 4.3, the dyke system is concentrated in the west regions with agricultural land use, some residential zones in the northern and west southern. Further, the dyke system combines and joins with the street system so that a protection network for tide flood is available in those areas.

The result of the DTM that presents all elevation information of the ground objects such as roads and buildings has some differences to the available researches in Ho Chi Minh City. In the available researches that consider of flood phenomenon in Ho Chi Minh City they are used DEM that is raster format for input to present the ground surface to implement of a flood model to determine floodplain, depth and other characteristics (ADB, 2009a; ADB, 2009b; Nhat, 2011; Storch & Downes, 2011; WB, 2010). However DEM is not able to integrate the ground objects that have the size smaller than the resolution of the DEM such as streets, dikes…. As a result the output of the flood model will not have high accuracy especially with flood caused by high tide these ground objects are very important because a lot of tide height is lower than elevation of the ground objects.

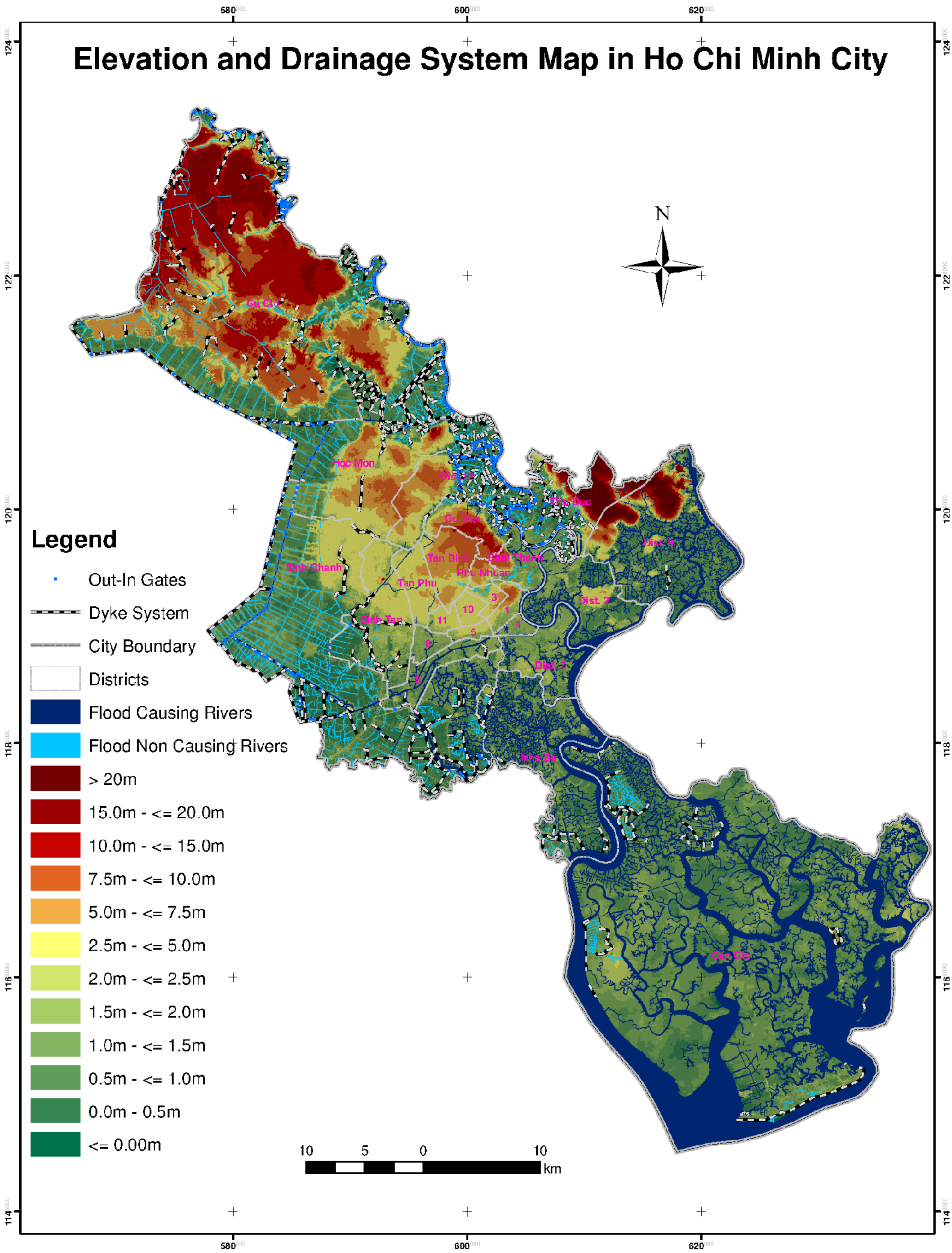


Fig. 4.3: Digital Terrain Model and drainage system in Ho Chi Minh City

6.2. Flooded area maps

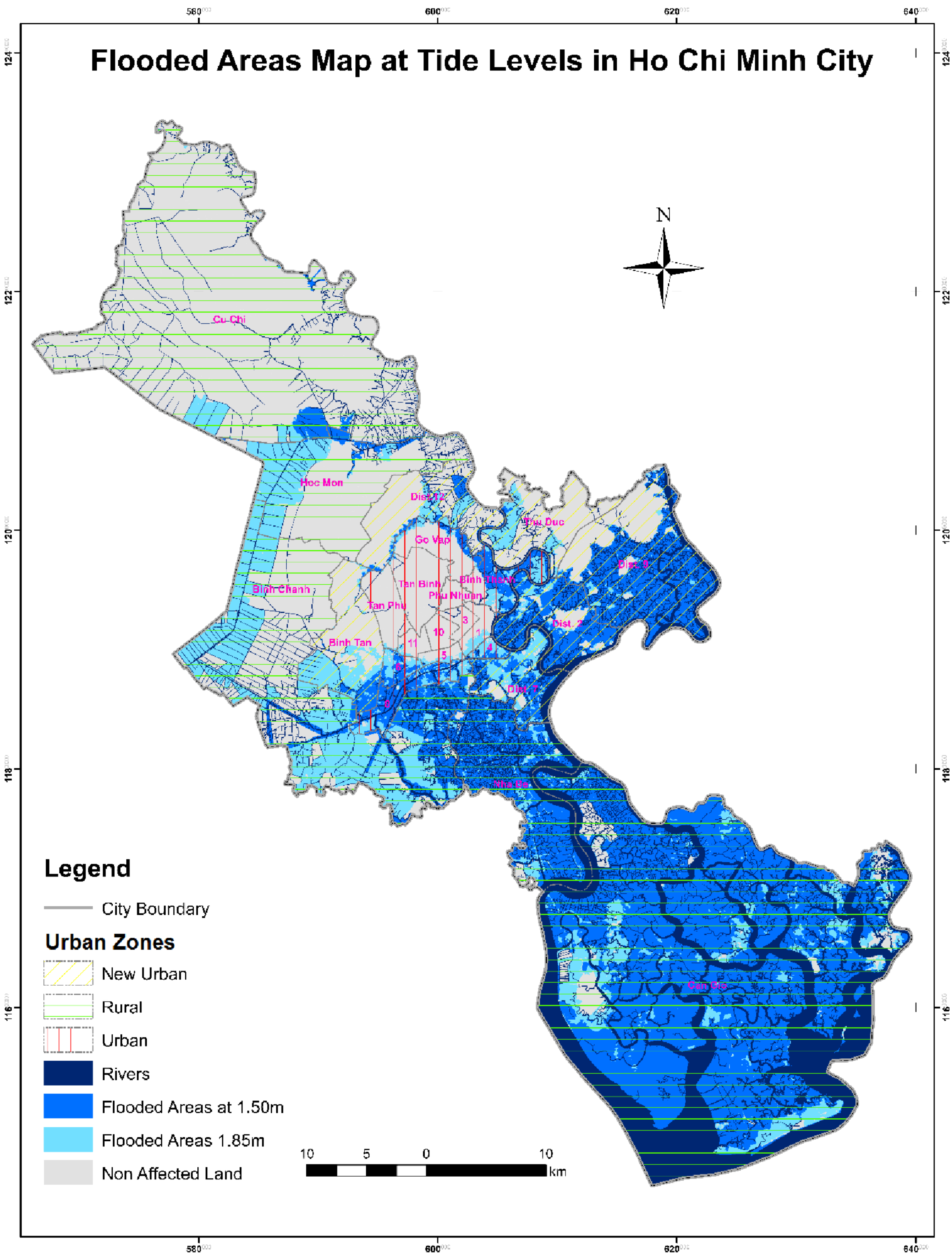


Fig. 4.4: Flooded area map at the tide levels in urban zones Ho Chi Minh City

Flooded area map is a map that shows flooding prone area in the study area at the tide level (TL). To generate the flooded area map the research identifies flooding locations based on the flowchart of figure 4.2. The identification of flooded areas is very important because they are input data for spatial analysis to assess of flood impact and calculate the damage and risks in the present and future. Moreover, to identify impact grades for different regions, the research classifies Ho Chi Minh City to three urban zones (PMVG, 1997; PMVG, 2003). The first zone is called old center urban which includes the old city center and districts. The second zone is called new urban which includes the new districts that are separated from the old rural. And the last one is calls rural which the rest of Ho Chi Minh City is. The classification performs the urbanization history in Ho Chi Minh City. Therefore this shows impacts of the urbanization to land use changes and somehow the changes will impact to flood risk. That is the research need to expose.

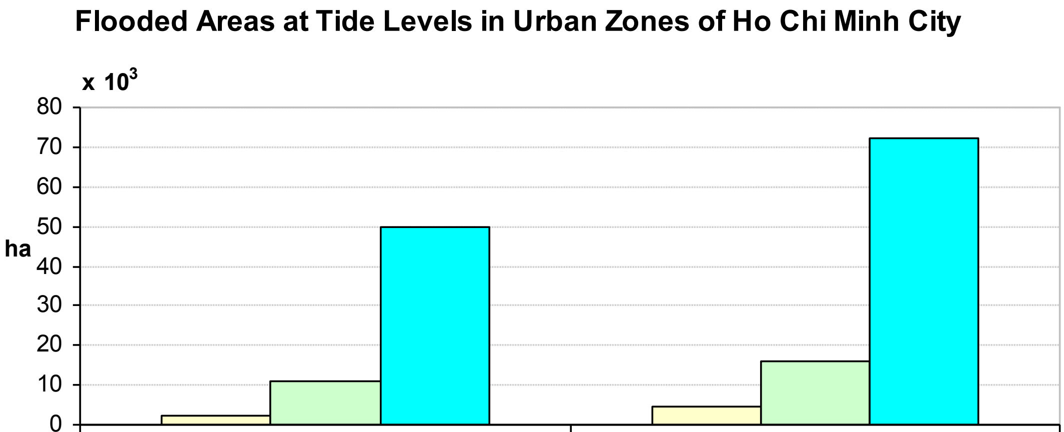
The flooded areas at the tide levels 1.5m and 1.85m are shown in the figure 4.4. The most difference at the tide levels is western and west southern regions with agricultural land use. At the tide level 1.5m, almost area in this region is not flooded, however as tide level emerged to 1.85m flood comes to this region. The cause is street and road elevations in the region are below 1.85m. The other changes at these tide levels are appearance some residential areas in the east northern of Thu Duc district and in the south of the district 7 and Can Gio.

Tab. 4.1: Flooded areas at the tide levels in urban zones of Ho Chi Minh City

No	Urban Zones	Code	Flooded Areas				Total Areas (ha)
			TL 1.50m		TL 1.85m		
			ha	%	ha	%	
3	Old Center Urban	URB	2,102	3.3	4,488	4.8	13,412
2	New Urban	NUR	10,804	17.2	15,969	17.2	31,065
1	Rural	RUR	50,026	79.5	72,239	77.9	133,819
Total			62,931	100.0	92,695	100.0	178,296

To see insight distribution the flooded areas in Ho Chi Minh City, the figure 4.5 and table 4.1 will show for this goal. Data in the table 4.1 shows that the flooded areas increase gradually from urban to new urban and then rural at two tide levels 1.50m and 1.85m. The flooded areas in the rural hold the most because almost areas in this region are mango forest in Can Gio rural district and rice - crop fields in southern regions of Binh Chanh rural district.

The flooded area in the rural at tide level 1.50m makes up 80%, that of in the new urban does 17% and 3% that in urban does. This shows that at the tide level 1.50m almost flooded area is agricultural land in the southern regions so that it only impacts to farmers who do on the rice –crop fields. At tide level 1.85m, the flooded area distribution is similar to at the tide level 1.50m. In the rural, the flooded areas is also major and then that is less than in new urban and the least one is urban with making up for each of them ordinarily 78%, 17% and 5%. There are changes with few percents of the flooded areas are reduced in the rural and increased in the urban.



	Tide level 1.50m (ha)	Tide level 1.85m (ha)
Old Center Urban	2102	4488
New Urban	10804	15969
Rural	50026	72239

Fig. 4.5: Flooded areas at the tide levels in urban zones of Ho Chi Minh City

Therefore, there is an augmentation of flooded area. At tide level 1.85m the flooded area is nearly 1.5 times as much as that does at tide level 1.50m. When the tide level comes higher, each of the urban zones is raised flooded area as shown in the chart of figure 4.5 and the table 4.1. About absolute values, the flooded area in rural is extended the most and that does the least in urban. In the rural, flooded area is extended in western regions of Binh Chanh rural district. The root is there are roads which have elevation that is higher tide level 1.50m but their elevations are lower than 1.85m so that those regions are flooded when tide level reaches to 1.85m. However, percentage increasing of flooded area in urban is the most with 2.1 times. The root is there are many district in urban with low lands in Binh Thanh, District 4 but the low lands are protected by the roads at tide level 1.50m and at tide level 1.85m they will be new extended flooded areas.

6.3. Flooding depth modeling for the research

Flooding deep map is a map that shows depth values of flooding prone areas in the study area at the specific tide level. The depth values are vertical differences between terrain elevation and tide level. Similarly to duration map of flooding, the element of depth of flooding will bring more information to assess the extent of flood risk to the probability of the human loss and property damage caused by flooding.

6.3.1 Method

The flooding depth can be calculated differently by types of applied flood model. For the flood models that use hydraulic model when wave equations are solved the flooding depth at each pixel of DEM is known (Aronica, Tucciarelli and Nasello, 1998; Horritt & Bates, 2002; Lai, 2005; Nien, 1996; NSWDOC-MHL, 2006). For the flood models that do not use any hydraulic model, the flooding depth is computed based on DEM and water level at each pixel of DEM if DEM is used as an input (Bates, 2004; Bates & De Roo, 2000; Nhat, 2011). With the second case, the flooding depth is carried out very simply in a GIS environment. Because of this reason, some researches when computation of the flooding depth a convert from TIN to DEM is preprocess. However, this processing will lose accuracy of the TIN. To keep the strength point of the TIN, this research computes flooding depth directly from TIN that there is not converted from TIN to DEM. The procedure is conducted as followings.

To determine flooding depth, the model uses the difference between interested tide level and terrain elevation in TIN. The interested regions for computation of flooding depth are the flooded areas where are defined as shown in the flowchart 4.2.

The computation process of the flooding depth includes following steps. Based on TIN, the terrain elevation is presented. At the interested tide level H_t, the flooding depth is calculated by using H_t subtracts terrain elevation. If the different values are positive that means the terrain elevation is lower than H_t and if the different values are negative that means the terrain elevation is higher than H_t. The regions whose different values are positive are able to inundate. However if the regions are connected to the rivers and canals causing flood they are the flooded areas. By run the flowchart 4.2 for these regions the result will determine the flooded areas enclosed the different values or the flooding depth.

Thus in the TIN to compute flooding depth and make a flooding depth map the first step is determination the grades that provide the boundaries of the flooding depth for each grade. And then based on the boundaries of the each grade, a computation at a flooding depth for each grade is carried out. And consequently, when completing of the computation, the regions matching to each grade of the flooding depth will be created. The dividing the flooding depth grades in the research are described and explained in the section 6.3.2.

6.3.2 Result and discussion

To be convenient in the flood risk assessment, the research classifies of flooding depth to depth grades. These depth grades are based on dangerous levels to human being in the study area. Consequently, there are four depth grades are considered.

- Depth grade 1 (D1): In the grade, the depth is above 0.0m and below 0.5m. This is the least dangerous to the human being there.
- Depth grade 2 (D2): In the grade, the depth is from 0.5m to below 1.2m. This is the grade that can be dangerous to children and elderly people.
- Depth grade 3 (D3): In the grade, the depth is from 1.2m to below 1.8m. This is the grade that does not only damage properties but also is dangerous to almost human living there.
- Depth grade 4 (D4): In the grade the depth is more 1.8m. Almost people can not living in this area if there is not any preparation for life conditions when flood appears.

Separation of the flooding depth characteristic to different grades is to assess reliability of human and properties that are impacted by flood in the study area. This is distinguished of this research with the available researches. The available researches, the flooding depth is also divided to the grades but they only aim to display on maps (ADB, 2009a; ADB, 2009b; ADB, 2009c; WB, 2010) and not for assessment of flood risk grades to the human being or the properties.

In order to identify impact depth grades of the flood risk for different regions, the depth characteristic will be assessed based on three urban zones similar to flooded area. The first zone is called old center urban which includes the old city center and districts. The second zone is called new urban which includes the new districts that are separated from the old rural (PMVG, 1997; PMVG, 2003). And the last one is calls rural which the rest of Ho Chi Minh City is. The classification performs the urbanization history in Ho Chi Minh City. Therefore this shows impacts of the urbanization to land use changes and somehow the changes will impact to flood risk. That is the research need to expose.

From the figure 4.6 and table 4.2, at the tide level 1.50m the most of flooded areas are flooding depth grade 1 and 2 with more than 98%, and the major portion for each of them is concentrated in the forest and field areas. The residential areas are not too much impacted. The grade 3 and grade 4 are very small parts distribution in the areas closing with the rivers. This shows at the tide level no much dangerousness relates to human living there.

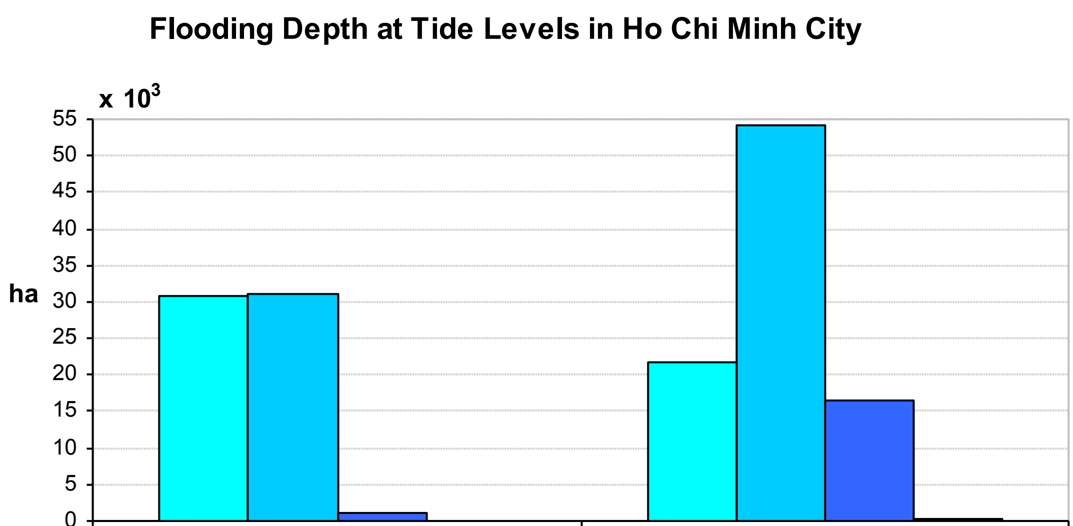
Tab. 4.2: Flooded areas of flooding depth grades at the tide levels in Ho Chi Minh City

No	Depth	Code	Flooded Areas			
			TL 1.5m		TL 1.85m	
			ha	%	ha	%
1	0 -0.5m	D1	30,771	48.9	21,687	23.4
2	0.5 - 1.2m	D2	31,033	49.3	54,150	58.4
3	1.2 -1.8m	D3	1,058	1.7	16,634	17.9
4	Deeper 1.8m	D4	69	0.1	224	0.2
Total			62,931	100.0	92,695	100.0

With the tide level 1.85m, flooded area percentage of the depth grade 1 is reduced to 23% but there is a significant change in the grade 2 to 58% and grade 3 is also increased to 18%. That shows flood risk is increasing much. Besides, grade 4 also increase if compared with the tide level 1.5m. A notice is flooded areas of depth grade 1 reduced but that of the grade 2 and the grade 3 speeded up. That means elevation in the flooded regions is very low but the regions are not inundated because of the roads. But the roads can not help for the regions prevented when tide level reach 1.85m so that the regions come to deep flooded areas. Almost flooded area of the depth grades is extended exceptionally that of the depth grade 1 is reduced when tide rising from

1.50m to 1.85m. Especially, the flooded area of depth grade 3 is increased rapidly from 1058ha at tide level 1.50m reach to 16634ha at tide level 1.85m. This is caused by movement of flooded area of the depth grade 2 at tide level 1.50m besides one portion of the new flooded areas is inundated very deep.

To explain and deeper understand on the data in the table 4.2, the results in the figure 4.7, figure 4.7, figure 4.8 and table 4.3 show distribution of flooded areas in the urban zones to expose the reasons. Decreasing flooded areas at the grade 1 happens in the rural because the rural is fair flat and low so that when tide level raises flat and low land will be flooded at the grade 2 and flooded areas at the grade 1 at tide level 1.50m are moved to grade 2 thus number of flooded areas at the grade 2 is increased quickly and number of flooded areas at grade 1 is reduced. In the new urban zone, when tide level raises the number of flooded areas at all grades is increased absolute values but they are not large.



	Tide level 1.5m (ha)	Tide level 1.85m (ha)
0 -0.5m	30771	21687
0.5 - 1.2m	31033	54150
1.2 -1.8m	1058	16634
Deeper 1.8m	69	224

Fig. 4.6: Flooded areas of flooding depth grades at the tide levels in Ho Chi Minh City

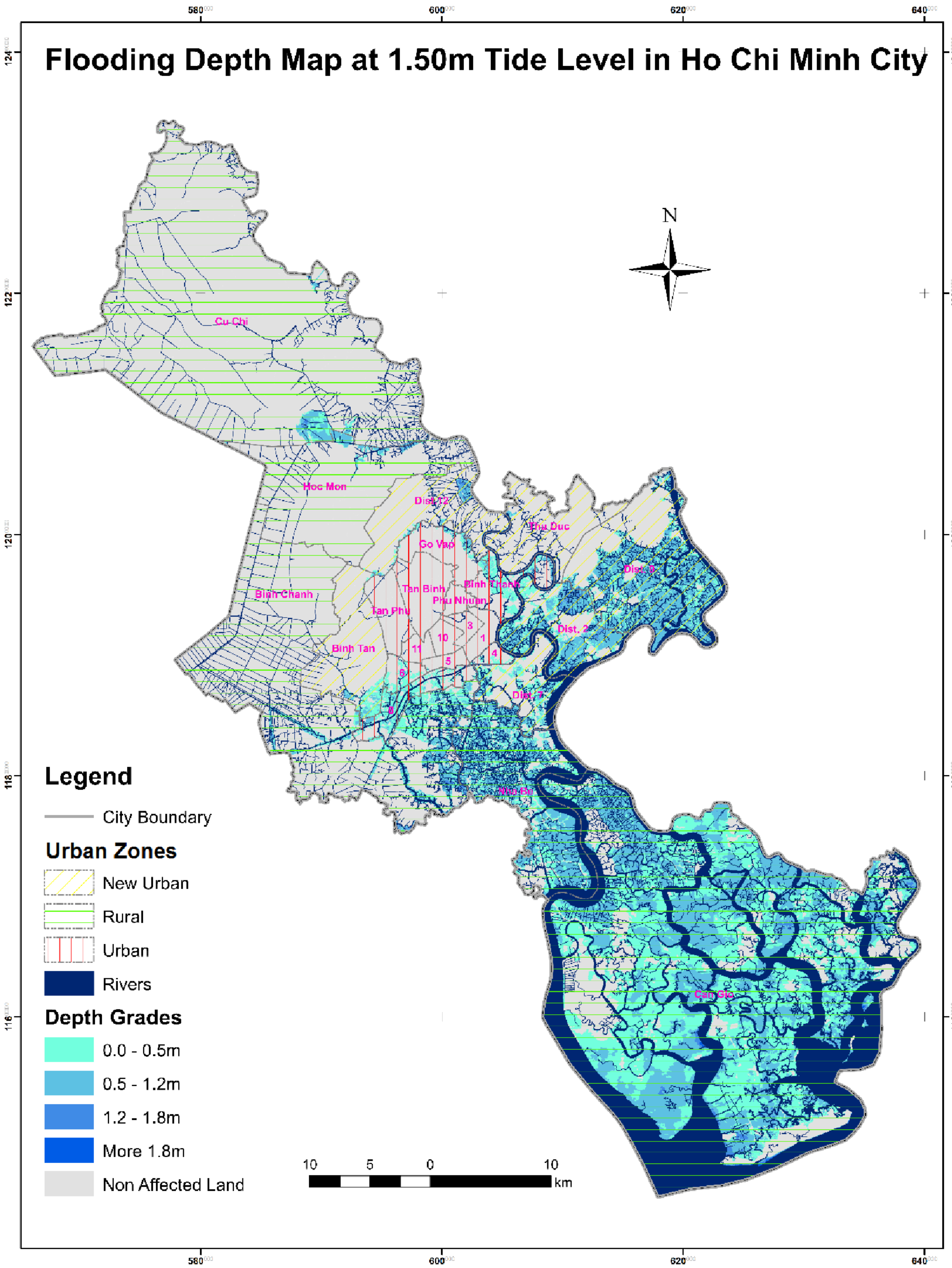


Fig. 4.7: Flooding depth maps at 1.50m tide level in urban zones Ho Chi Minh City

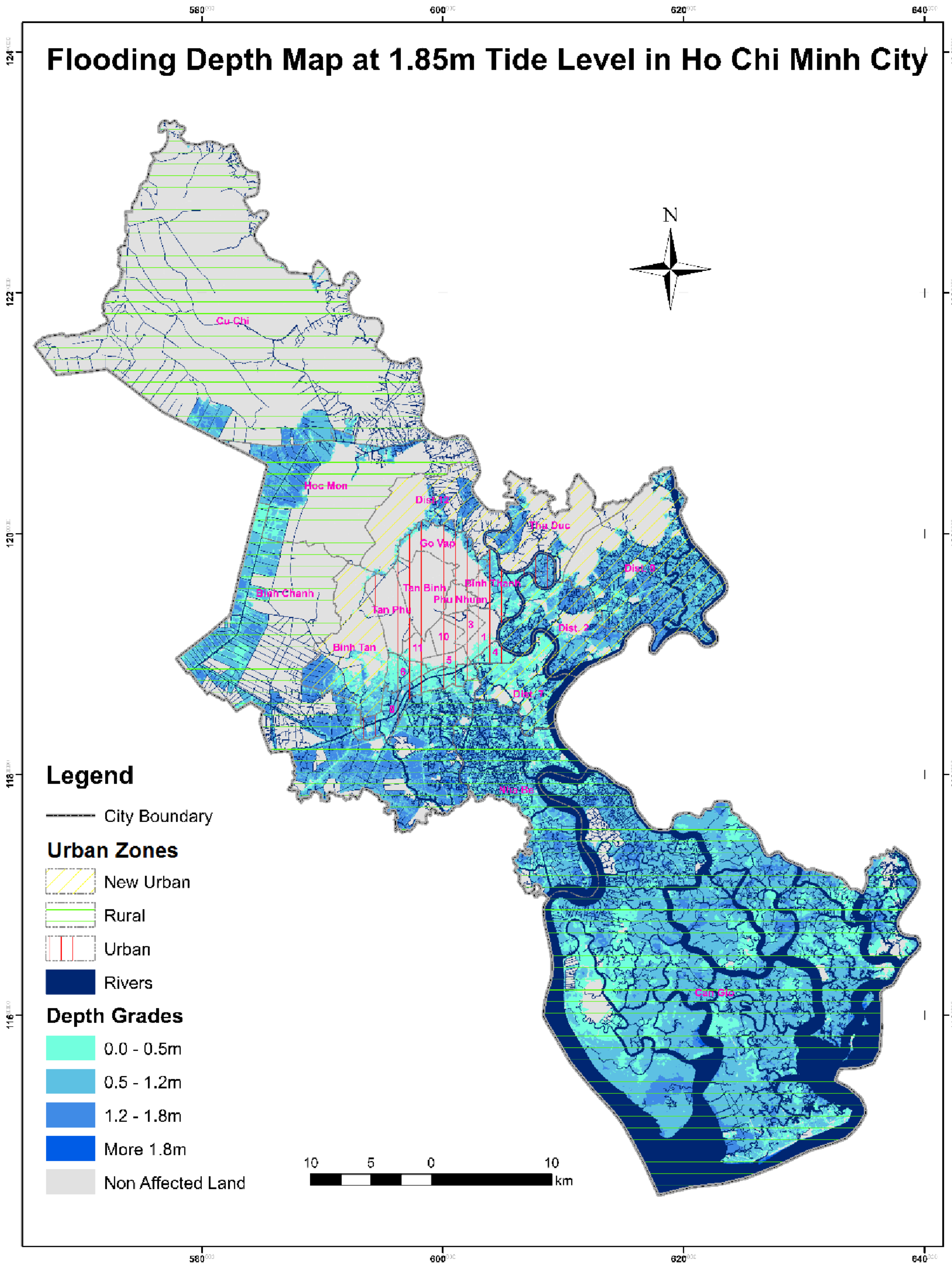


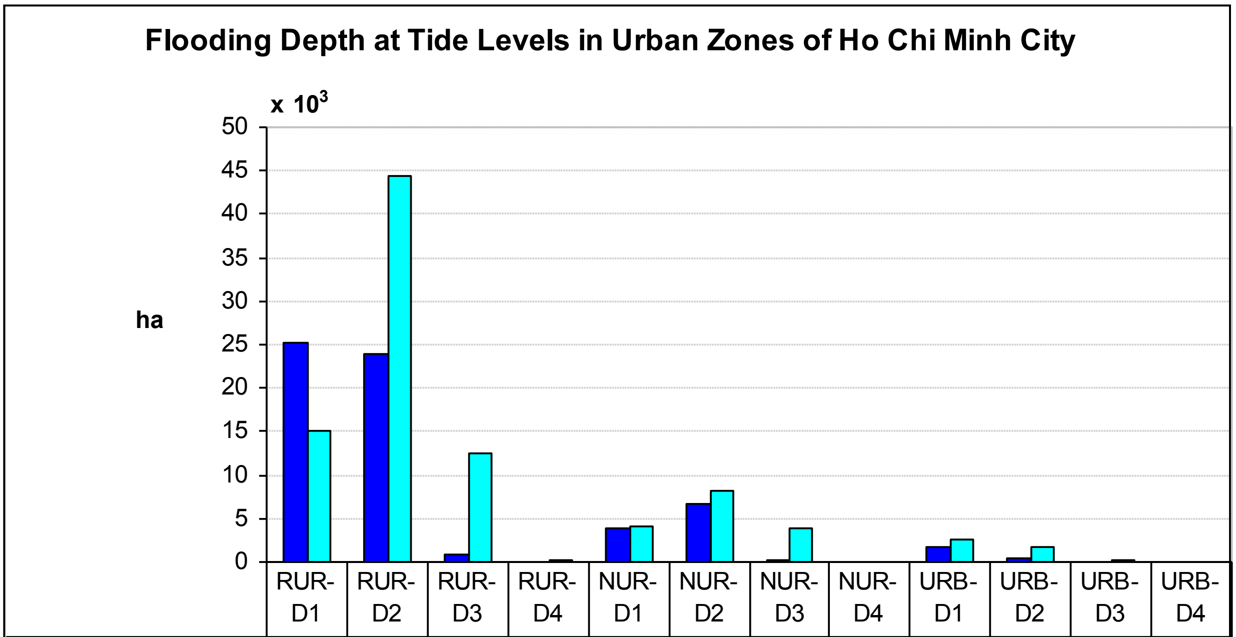
Fig. 4.8: Flooding depth maps at 1.85m tide level in urban zones Ho Chi Minh City

The flooded area at grade 3 is increased strongly in all the urban zones at tide level 1.85m. The first reason is the old center urban at the tide level 1.50m flooded areas at grade 1 and grade 2 are moved to grade 3 at the tide level 1.85m and more new flooded areas at tide level 1.85m are low land in Binh Thanh District, District 8, District 6 and District 4 so that the new flooded areas are inundated deep in the grade 3. The second reason is the rural and new urban are low land so that the new flooded areas will be inundated deep at the grade 3. The last reason is protection of roads for the new flooded areas at tide level 1.50m but when tide level raises the roads can not ensure for the low land preventing inundation and the areas will be deep flooded at the grade 3 (shown in figure 4.7 and figure 4.8).

Tab. 4.3: Flooded areas of flooding depth grades at the tide levels in urban zones of Ho Chi Minh City

No	Urban Zones	Depth	Code	Flooded Areas			
				TL1.50m		TL 1.85m	
				ha	%	ha	%
1	Rural	0 -0.5m	RUR-D1	25,178	40.0	15,137	16.3
2	Rural	0.5 - 1.2m	RUR-D2	24,007	38.1	44,309	47.8
3	Rural	1.2 -1.8m	RUR-D3	772	1.2	12,588	13.6
4	Rural	Deeper 1.8m	RUR-D4	68	0.1	204	0.2
5	New Urban	0 -0.5m	NUR-D1	3,821	6.1	3,996	4.3
6	New Urban	0.5 - 1.2m	NUR-D2	6,700	10.6	8,169	8.8
7	New Urban	1.2 -1.8m	NUR-D3	282	0.4	3,785	4.1
8	New Urban	Deeper 1.8m	NUR-D4	1	0.0	19	0.0
9	Old Center Urban	0 -0.5m	URB-D1	1,772	2.8	2,554	2.8
10	Old Center Urban	0.5 - 1.2m	URB-D2	326	0.5	1,673	1.8
11	Old Center Urban	1.2 -1.8m	URB-D3	4	0.0	261	0.3
12	Old Center Urban	Deeper 1.8m	URB-D4	0	0.0	0	0.0
Total				62,931	100.0	92,695	100.0

Based on the results once again the terrain is not much fluctuation so that when the tidal height change flooded area has a significant rise. A note is new flooded areas are concentrated in the residential regions although flooding depth is grade 1 but people living there need to be careful for their activities.



	RUR-D1	RUR-D2	RUR-D3	RUR-D4	NUR-D1	NUR-D2	NUR-D3	NUR-D4	URB-D1	URB-D2	URB-D3	URB-D4
Tide level 1.50m (ha)	25178	24007	772	68	3821	6700	282	1	1772	326	4	0
Tide level 1.85m (ha)	15137	44309	12588	204	3996	8169	3785	19	2554	1673	261	0

Fig. 4.9: Flooded areas of flooding depth grades at the tide levels in urban zones of Ho Chi Minh City

6.4. Flooding duration modeling for the research

Flooding duration map is a map that shows duration values at a location in the flooding prone areas from starting to end time point of a flood. This characteristic is not usually considered much in the output of the flood models because almost the flood models concentrate to other characteristics including floodplain, depth and flow velocity (NSWDOC-MHL, 2006; Rossman, 2009). By the reason, the available researches on the flood in the study area are the same situation (ADB, 2009a; ADB, 2009b; ADB, 2009c; Nhat, 2011; Storch & Downes, 2011; WB, 2010). However, flood phenomenon in Ho Chi Minh City caused by tide with sea level rise in the future needs to consider to this characteristic more because this characteristic impacts to many aspects and fields. Therefore consideration to the characteristic is useful for estimation flood risk.

In the case, the flooding duration is time value at a location in the flooding prone area from starting to end time point of a flood at the tide level. The flooding duration map is based on the flooded area map combining with the flood deep map and tide data chain. To determine time period of duration, the tide data chain records will be used to define tide height relating with its time. The element of duration of flooding will bring more information to assess the extent of flood risk to the probability of the human loss and property damage caused by flooding.

6.4.1 Method

For the flooding duration, processing is more complicated because requirement of combination between tide duration, tide level and terrain elevation in TIN. This processing requires a consideration of continuous tide level in a cycle on duration progress to determine starting time and ending time of a flooded location.

The computation process of the flooding duration includes following steps. The first step is analysis of progress for tide level and duration. At each interested tide level H_t. the first one records starting time T_s when the tide level reaches H_t on the increasing tide level of the cycle. Similarly on the decreasing tide level of the cycle, when the tide level comes down to H_t, ending time T_e is recorded. The flooding duration at tide level H_t of a location is computed by subtracting T_e with T_s. The process is conducted for all tide levels and as a result, a table which shows relationship between tide level H and duration T called table H-T is created. Then a join between the tables H-T to terrain elevation TIN is implemented so that each of location in terrain is connected to a duration value. At each of interested tide level of the research, the flowchart 4.1 is run. This step is carried out because of elimination of locations where is not one of the flooded areas at the tide level.

The process of this flood characteristic is very complicated because it needs much more time and computation cost than flooding depth characteristic besides there are many tide levels matching to terrain elevation and at each of the tide level the flowchart 4.2 must be run to attach flooding duration value to the terrain elevation.

6.4.2 Result and discussion

Similarly to the depth characteristic of flood, because of convenience of assessment the research classifies of flooding duration to grades. These duration grades are based on impact levels to living activities of the residents in the study area. Consequently, there are five depth grades are considered.

- Duration grade 1 (T1): In the grade, the duration lasts less than 1 hour. This does not impact too much to living activities of the residents in the study area and the time compensation of work can be modify.
- Duration grade 2 (T2): In the grade, the duration lasts more 1 hour and less than 2 hours. This appears some postponements of regular work planning to living activities of the residents.
- Duration grade 3 (T3): In the grade, the duration lasts more 2 hours and less than 3 hours. This appears more delay of regular work planning to living activities.
- Duration grade 4 (T4): In the grade, duration lasts more than 3 hours and less than 4 hours. This is really difficult to plan daily works.
- Duration grade 5 (T5): In the grade, duration lasts more than 4 hours that means more than half of workday is out of. The daily work is serious impacted. Consequently there are many aspects of life can be related.

In order to identify impact duration grades of the flood risk for different regions, the duration characteristic will be assessed based on three urban zones similar to flooded area. The first zone is called old center urban which includes the old city center and districts. The second zone is called new urban which includes the new districts that are separated from the old rural (PMVG, 1997; PMVG, 2003). And the last one is calls rural which the rest of Ho Chi Minh City is. The classification performs the urbanization history in Ho Chi Minh City. Therefore this shows impacts of the urbanization to land use changes and somehow the changes will impact to flood risk. That is the research need to expose.

For flooding duration, data in the table 4.4 and figure 4.10 shows that at the higher grades the more flooded areas are at all two tide levels. But especially almost number of flooded areas is concentrated at the highest grade. The reason is almost flooded areas are low land with the mango forest and rice – crop fields so that these regions are inundated at the highest grade of flooding duration.

Tab. 4.4: Flooded areas of flooding duration grades at the tide levels in Ho Chi Minh City

No	Frequency	Code	Flooded Areas			
			TL 1.50m		TL 1.85m	
			ha	%	ha	%
1	Less 1 t/m	F1	10,089	16.0	12,966	14.0
2	1 - 3 t/m	F2	5,336	8.5	6,302	6.8
3	3 - 7 t/m	F3	6,679	10.6	10,505	11.3
4	More 7 t/m	F4	40,827	64.9	62,921	67.9
Total			62,931	100.0	92,695	100.0

There is increases flooded area at almost of flooding duration grade when tidal level changes from 1.5m to 1.85m exceptionally grade 1. This result points out the developing flooded areas at tide level 1.85m in regions where are higher than 1.50m are not so much or other words in Ho Chi Minh City there is not so much land where has ground elevation higher than 1.50m.

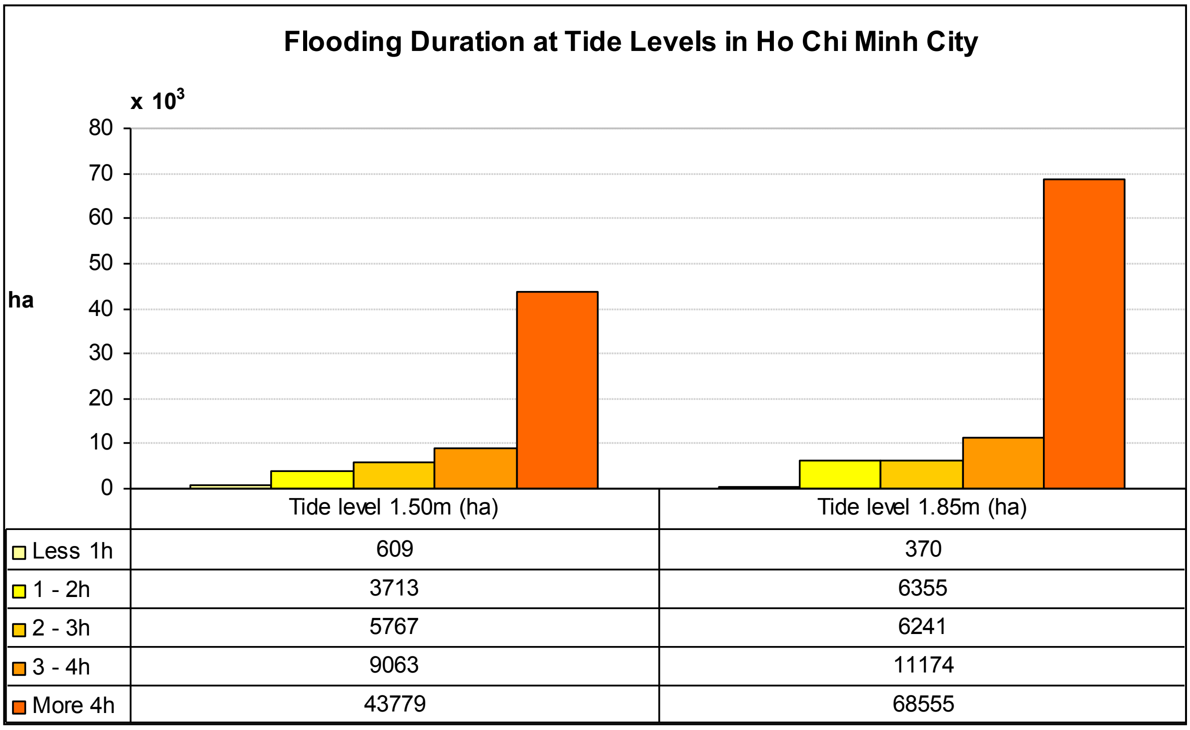


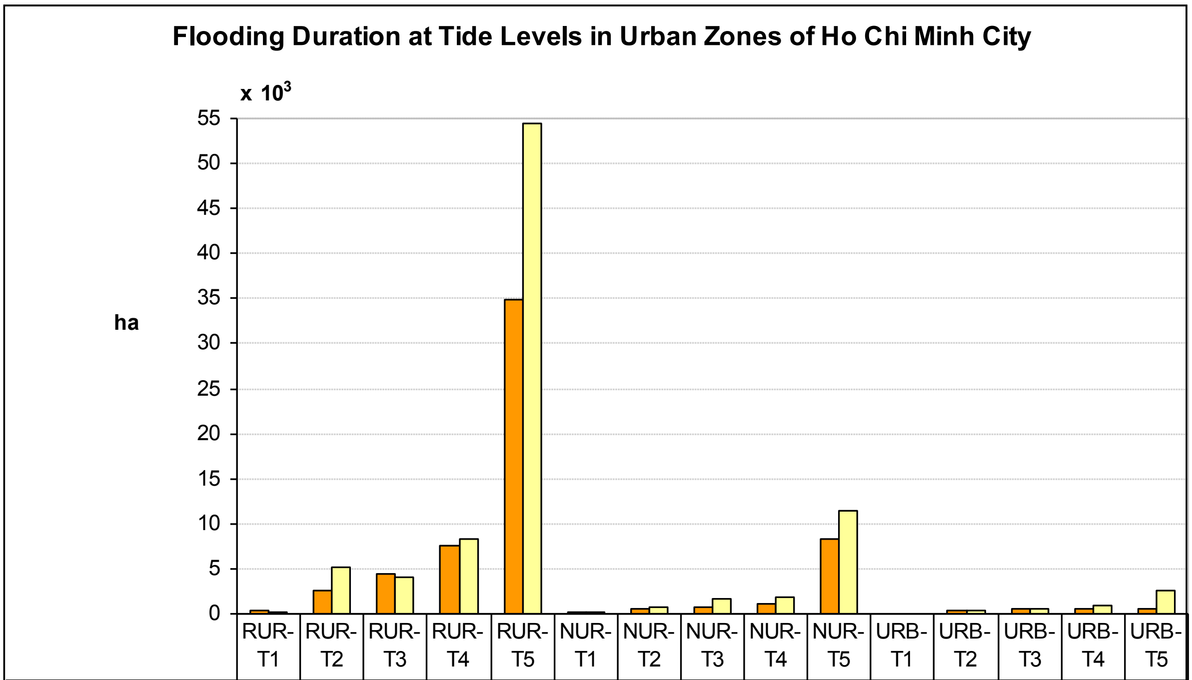
Fig. 4.10: Flooded areas of flooding duration grades at the tide levels in Ho Chi Minh City

Moreover, the new flooded areas are almost low land and protected by roads whose heights are not so different with tide level 1.50m so that the number of the new flooded areas at grade 4 at tide level 1.80m equals to 1.5 time as many as that of tide level 1.50m.

Tab. 4.5: Flooded areas of flooding duration grades at the tide levels in urban zones of Ho Chi Minh City

No	Urban Zones	Duration	Code	Flooded Areas			
				TL 1.50m		TL 1.85m	
				ha	%	ha	%
1	Rural	Less 1h	RUR-T1	410	0.7	96	0.1
2	Rural	1 - 2h	RUR-T2	2,668	4.2	5,165	5.6
3	Rural	2 - 3h	RUR-T3	4,486	7.1	4,079	4.4
4	Rural	3 - 4h	RUR-T4	7,496	11.9	8,384	9.0
5	Rural	More 4h	RUR-T5	34,966	55.6	54,515	58.8
6	New Urban	Less 1h	NUR-T1	147	0.2	235	0.3
7	New Urban	1 - 2h	NUR-T2	612	1.0	771	0.8
8	New Urban	2 - 3h	NUR-T3	796	1.3	1,644	1.8
9	New Urban	3 - 4h	NUR-T4	1,035	1.6	1,855	2.0
10	New Urban	More 4h	NUR-T5	8,214	13.1	11,464	12.4
11	Old Center Urban	Less 1h	URB-T1	53	0.1	39	0.0
12	Old Center Urban	1 - 2h	URB-T2	434	0.7	420	0.5
13	Old Center Urban	2 - 3h	URB-T3	484	0.8	518	0.6
14	Old Center Urban	3 - 4h	URB-T4	532	0.8	936	1.0
15	Old Center Urban	More 4h	URB-T5	599	1.0	2,576	2.8
Total				62,931	100.0	92,695	100.0

To explain and deeper understand which urban zones are impacted on the flooding duration, the results in the figure 4.11, figure 4.12, figure 4.13 and table 4.5 answer and expose this matter. As above mentions, the rural zones are inundated in the mangrove forest and rice – crop fields. And similarly the new urban zones are inundated in the low rice – crop fields. Therefore, the figure 4.11 and table 4.5 show flooded areas of the high flooding duration grades in the new urban zones more than that of the old center urban. Moreover number of flooded areas at the higher grades is increased more. Besides low land cause, the tide characteristic in Ho Chi Minh City with average tide level more than 1.2m has long duration (appendix A.1).



	RUR-T1	RUR-T2	RUR-T3	RUR-T4	RUR-T5	NUR-T1	NUR-T2	NUR-T3	NUR-T4	NUR-T5	URB-T1	URB-T2	URB-T3	URB-T4	URB-T5
Tide level 1.50m (ha)	410	2668	4486	7496	34966	147	612	796	1035	8214	53	434	484	532	599
Tide level 1.85m (ha)	96	5165	4079	8384	54515	235	771	1644	1855	11464	39	420	518	936	2576

Fig. 4.11: Flooded areas of flooding duration grades at the tide levels in urban zones of Ho Chi Minh City

For the old center urban there are conclusions delivered. At the grade 1 and grade 2 when tide level rises from 1.50m to 1.85m, number of flooded areas is reduced but increased stably at the grade 4. This shows that increasing new flooded areas at the tide level 1.85m in the old center urban in the high land is not much otherwise the new flooded areas are low land and these areas are protected roads. The road elevations are not much higher than tide level 1.50m so that the low land is inundated at the high grade of flooding duration when tide level rises.

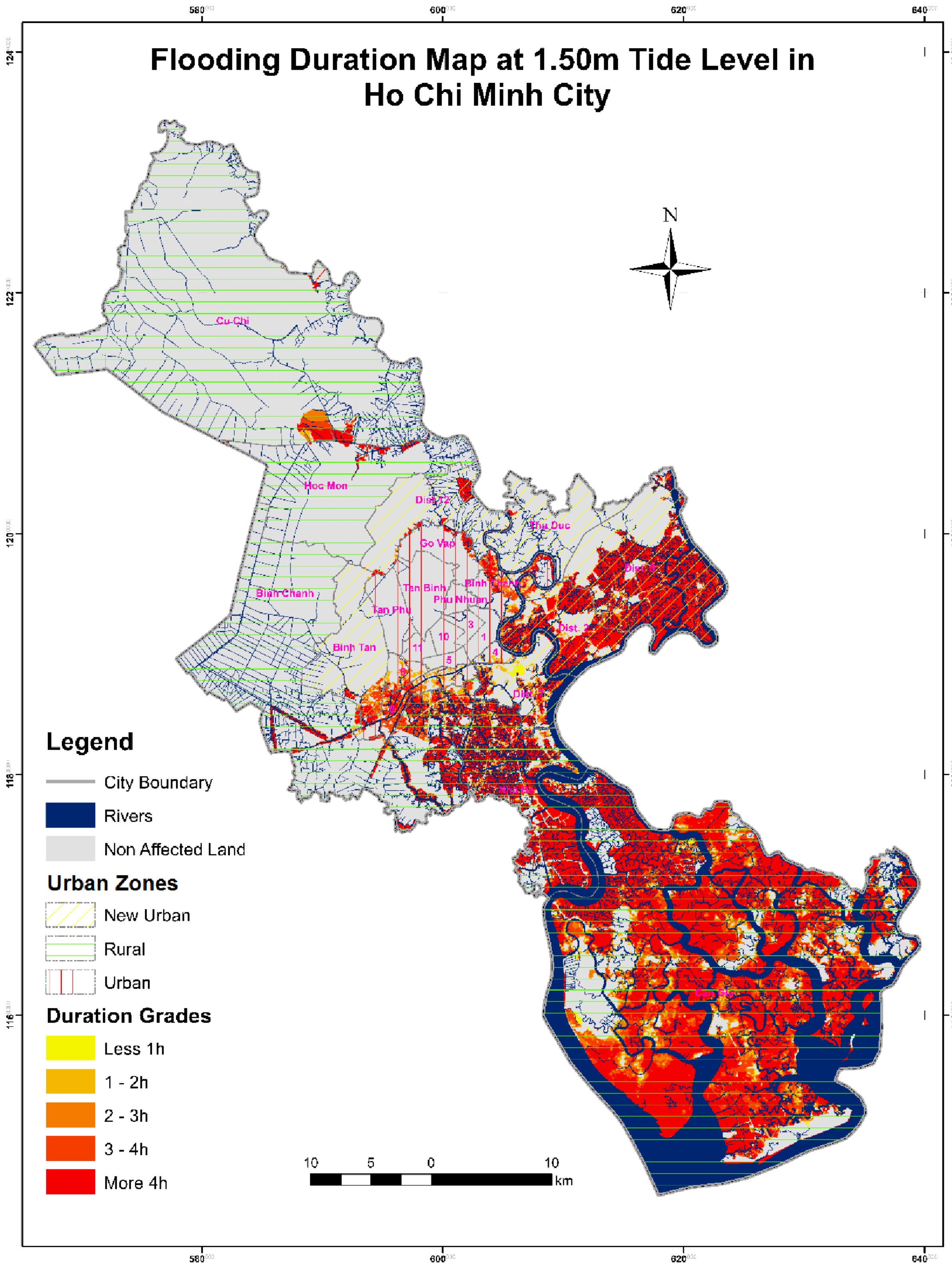


Fig. 4.12: Flooding duration maps at 1.50m tide level in urban zones of Ho Chi Minh City

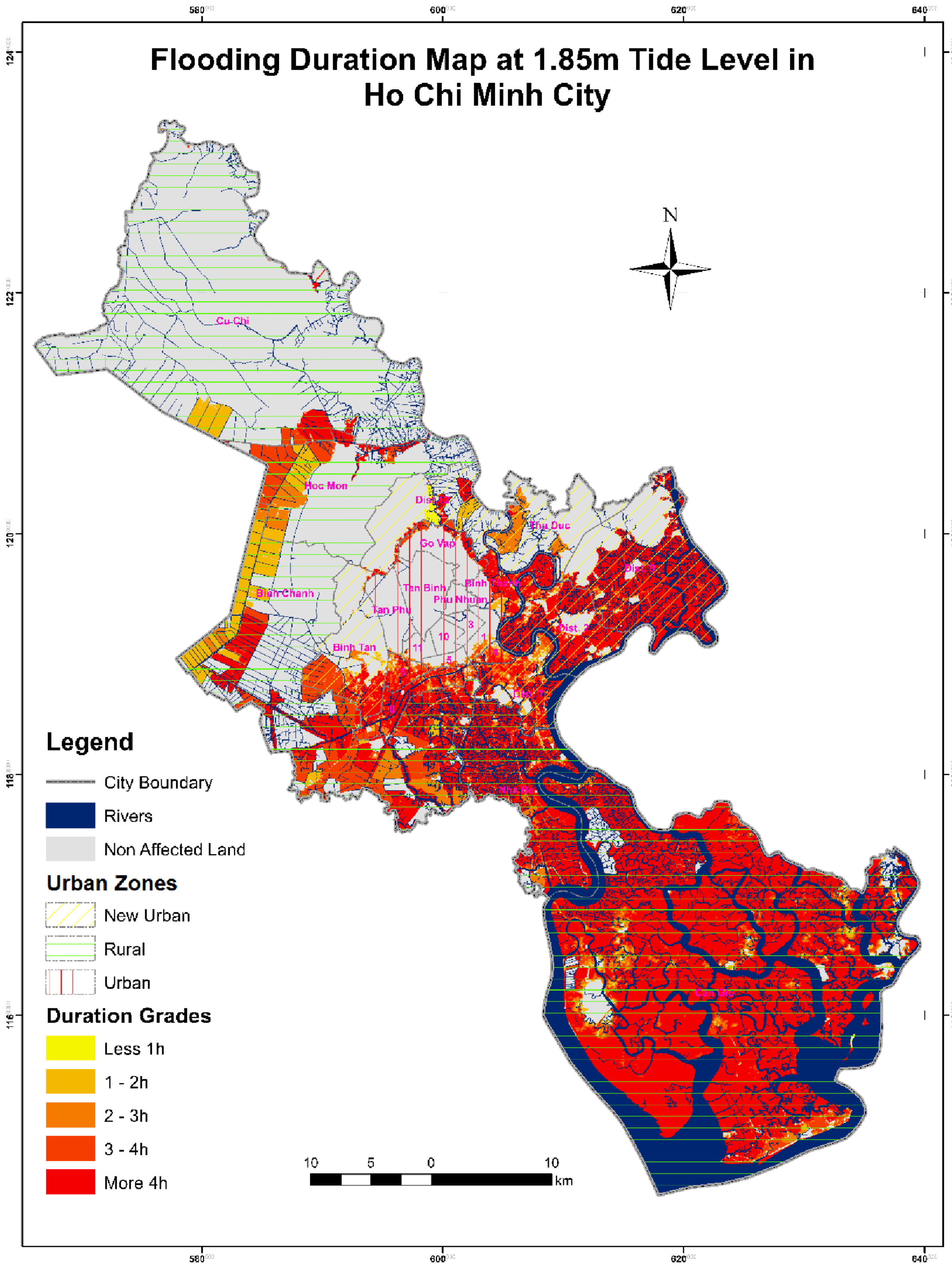


Fig. 4.13: Flooding duration maps at 1.85m tide level in urban zones of Ho Chi Minh City

Generally, at the tide levels flooded areas are classified to the grade 4 that means almost flooded areas is inundated for long time. However, these flooded areas shown in figure 4.12 and figure 4.13 are located on the forest and agricultural land. These regions are low lands and occupy many areas and as a result, these regions contribute to flooded area at the grade 4. For the residential regions, the flooding duration is grade 1. At the tide level 1.85m, a significant note for the residential regions in the Binh Thanh District, District 4, District 6 and District 8 should be more careful because the flooded areas in duration grade 4 increase rapidly.

6.5. Flooding frequency modeling for the research

Flooding frequency map is a map that shows frequent values in periods of time at locations in the flooding prone areas. Usually, flooding frequency characteristic is only interested with the appearance probability from observed data for a long time serial and the probability is applied mainly for designing protection structures (NSWDOC-MHL, 2006; Rossman, 2009). However, flood caused by tide is a phenomenon daily appearing certainly. Therefore, the research is considering appearance number of flood risk caused by tide based on the tide data record for time serial that is used to study climate change in Ho Chi Minh City to determine sea level rise in the time period.

Depended on the tide height, the flooding frequency map is established based on the floodplains of the flooded area map associated with frequency of tidal data chain at different tide levels. Similarly to duration and depth maps of flooding, the element of frequency of flooding will bring more information to assess the extent of flood risk to the probability of the human loss and property damage caused by flooding.

6.5.1 Method

With the traditional researches on the flood phenomenon, the flooding frequency characteristic is used for designing flood appearance probability depending on requirements that the flood impacts to human, social aspects and properties. This frequency is chosen from the past record serial of flood (NSWDOC-MHL, 2006; Rossman, 2009). However, with flood caused by tide in the future combining with the sea level rise, the flooding frequency characteristic needs to consider more detail. This is difference of this research compared with the available researches (ADB, 2009a; ADB, 2009b; ADB, 2009c; Nhat, 2011; Storch & Downes, 2011; WB, 2010).

Similarly to flooding duration characteristic, processing of the flooding frequency is also complicated because requirement of combination between tide frequency, tide level and terrain elevation in TIN. This processing requires a consideration of continuous tide level in a cycle on duration progress to determine starting time and ending time of a flooded location.

The computation process of the flooding frequency includes following steps. The first step is calculation for tide peaks H and their appearances F. The process is conducted for all peaks which appeared in the tide record data at the tide station for a period of reference time for climate change. In the research, the period of reference time is from 1980 to 1999. As a result, a table which shows relationship between tide peaks H and their frequency called table H-F is created. Then a join the table H-F to terrain elevation TIN is implemented so that each of location in terrain is connected to a frequency value. At each of interested tide level of the research, the flowchart 4.2 is run. This step is carried out because of elimination of locations where is not one of the flooded areas at the tide level.

The process of this flood characteristic is complicated because it needs much more time and computation cost than flooding depth characteristic besides there are many tide levels matching to terrain elevation and at each of the tide level the flowchart 4.2 must be run to attach flooding frequency value to the terrain elevation.

6.5.2 Result and discussion

Similarly to the other characteristics of flood, because of convenience of flood risk assessment the research classifies of flooding frequency to grades. These frequency grades are based on impact levels to living activities of the residents in the study area. Consequently, there are four frequency grades are considered.

- Frequency grade 1 (F1): In the grade, the frequency of flood appears less than 1 time per month. This does not impact too much to living activities of the residents in the study area.
- Frequency grade 2 (F2): In the grade, the frequency of flood appears more than 1 and less than 3 times per month. This begins to impact much about living activities of the residents in the study area. The residents living in the areas need solution for facing flood in their life.

- Frequency grade 3 (F3): In the grade, the frequency of flood appears more than 3 and less than 7 times per month. This impacts much to living activities of the residents in the study area.
- And the highest grade is 4 (F4). In the grade, the frequency of flood appears more than 7 times per month. That impact too much about living activities of the residents there.

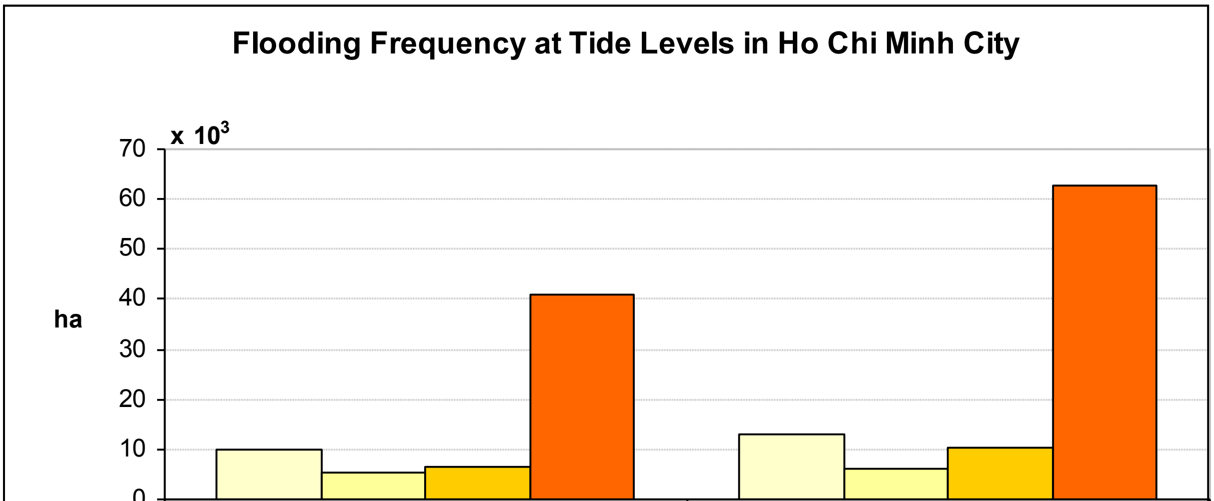
In order to identify impact frequency grades of flood risk for different regions, the flooding frequency characteristic will be assessed based on three urban zones similar to flooded area. The first zone is called old center urban which includes the old city center and districts. The second zone is called new urban which includes the new districts that are separated from the old rural (PMVG, 1997; PMVG, 2003). And the last one is calls rural which the rest of Ho Chi Minh City is. The classification performs the urbanization history in Ho Chi Minh City. Therefore this shows impacts of the urbanization to land use changes and somehow the changes will impact to flood risk. That is the research need to expose.

Tab. 4.6: Flooded areas of flooding frequency grades at the tide levels in Ho Chi Minh City

No	Frequency	Code	Flooded Areas			
			TL 1.50m		TL 1.85m	
			ha	%	ha	%
1	Less 1 t/m	F1	10,089	16.0	12,966	14.0
2	1 - 3 t/m	F2	5,336	8.5	6,302	6.8
3	3 - 7 t/m	F3	6,679	10.6	10,505	11.3
4	More 7 t/m	F4	40,827	64.9	62,921	67.9
Total			62,931	100.0	92,695	100.0

The analysis of flooding frequency grades will be started with data in the table 4.6 and chart in the figure 4.14. In general the flooding frequency there is different compared with the flooded characteristics. At two tide levels, flooded areas at grade 2 and grade 3 are less than the others. The grade 4 has the most flooded areas. The reason is almost forest and field areas in the southern are low land and not protected by structures so that the areas are inundated at the grade 4.

At the tide level 1.50m flooded areas account for 65% at grade 4, 16% at grade 1, 11% at grade 3 and the least at grade 2 with 8%. At the tide level 1.85m, distribution of the flooded areas is similar to tide level 1.50m but there is a little of difference account for each of grades. Number of flooded areas at grade 4 is increased to 68%, which of grade 1 is reduced to 14%, not change is grade 3 and the least is grade 2. When tide level rises, all flooding frequency grades increase flooded areas and there is not any grades reduced. In that increasing, the grade 3 is extended flooded area 1.6 times as many as tide level 1.50m. The grade 4 is extended 1.5 times. The reason to explain for this phenomenon is low land occupying almost areas. To analyze insight the phenomenon, data in table 4.7, figure 4.15 figure 4.16 and figure 4.17 shows that.



	Tide level 1.50m (ha)	Tide level 1.85m (ha)
Less 1 t/m	10089	12966
1 - 3 t/m	5336	6302
3 - 7 t/m	6679	10505
More 7 t/m	40827	62921

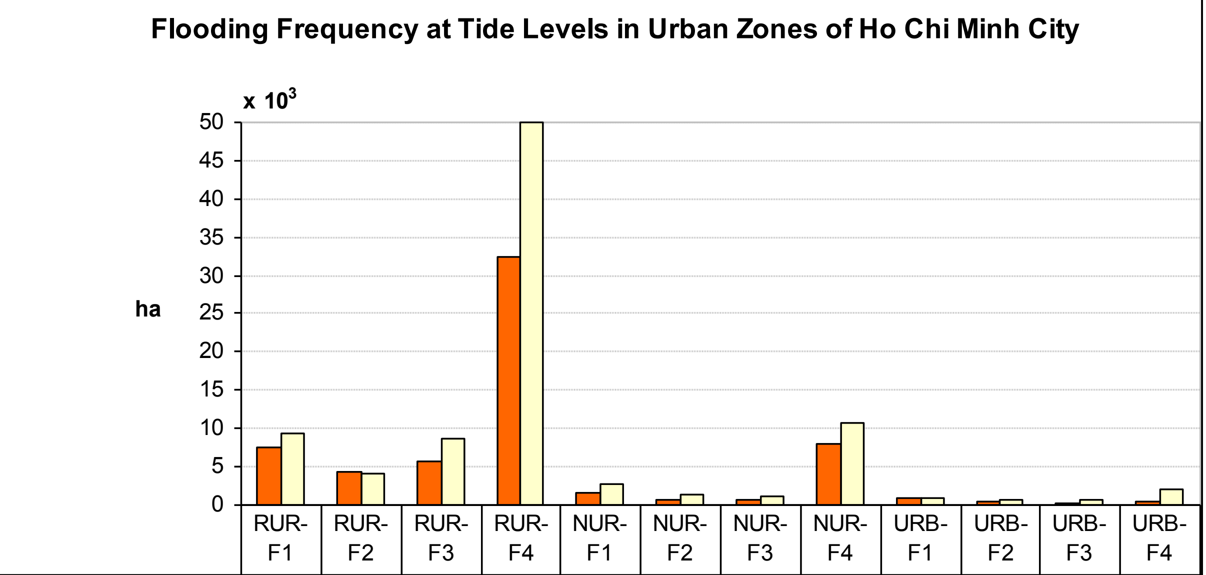
Fig. 4.14: Flooded areas of flooding frequency grades at the tide levels in Ho Chi Minh City

At the tide level 1.50m, the first thing is the rural zones have almost flooded area at the grade 4 and the other grades are not much different. In the new urban zones the grade 4 of flooding frequency still holds major portion but the flooded area at the grade 1 is increased and held more. And in the old center urban almost flooded areas are the grade 1 of flooding frequency. The cause is the rural and new urban are low and very low land regions so that flooded areas in these regions at the grade 4 holds major portion. The grade 1 is more than grad 2 and grade 3 because the value range of tide level matching with the grade 1 is much larger than that of the grade 2 and grade 3 (see Appendix A.2). For the old center urban, this region is higher land and has regular slope so that almost flooded areas are at the grade 1.

Tab. 4.7: Flooded areas of flooding frequency grades at the tide levels in urban zones of Ho Chi Minh City

No	Urban Zones	Frequency	Code	Flooded Areas			
				TL1.50m		TL1.85m	
				ha	%	ha	%
1	Rural	Less 1 t/m	RUR-F1	7,563	12.0	9,340	10.1
2	Rural	1 - 3 t/m	RUR-F2	4,297	6.8	4,199	4.5
3	Rural	3 - 7 t/m	RUR-F3	5,738	9.1	8,684	9.4
4	Rural	More 7 t/m	RUR-F4	32,427	51.5	50,016	54.0
5	New Urban	Less 1 t/m	NUR-F1	1,555	2.5	2,650	2.9
6	New Urban	1 - 3 t/m	NUR-F2	656	1.0	1,476	1.6
7	New Urban	3 - 7 t/m	NUR-F3	678	1.1	1,039	1.1
8	New Urban	More 7 t/m	NUR-F4	7,915	12.6	10,804	11.7
9	Old Center Urban	Less 1 t/m	URB-F1	971	1.5	976	1.1
10	Old Center Urban	1 - 3 t/m	URB-F2	383	0.6	627	0.7
11	Old Center Urban	3 - 7 t/m	URB-F3	263	0.4	782	0.8
12	Old Center Urban	More 7 t/m	URB-F4	485	0.8	2,102	2.3
Total				62,931	100.0	92,695	100.0

At the tide level 1.85m, there is much change in the old center urban and new urban. In the new urban, flooded area is increased all grades but the most is grade 2 and grade 1. The cause is movement from grade 1 to grade 2 when tide level rises from 1.50m to 1.85m. Besides, there are new flooded areas at the tide level 1.85m are low lands but they are protected by roads at tide level 1.50m so that when tide level reaches 1.85m these low lands are inundated at the grade 1. In the old center urban, an especial thing is flooded area increased at the grade 3 and grade 4 when tide level rises from 1.50m to 1.85m. There are two reasons to explain for this phenomenon. The first reason is terrain in some districts of the old center urban such as District 4, District 6, District 8 and Binh Thanh District is low but these regions of low terrain are protected by roads so that at the tide level 1.50m they are not inundated but flooded when tide level reaches 1.85m so that these regions will be flooded deep and almost flooded areas of these regions are grade 3 and grade 4. The second reason is characteristic of flooding frequency. In the appendix A.2, value range of tide levels matching with grade 3 and grade 4 is not much different that of grade 1 and grade 2 so that when tide level rises from 1.50m to 1.85m flooded areas at grade 1 and grade 2 are moved to grade 3 and grade 4. As a result, the flooded areas at the grade 3 and grade 4 are increased strongly.



	RUR-F1	RUR-F2	RUR-F3	RUR-F4	NUR-F1	NUR-F2	NUR-F3	NUR-F4	URB-F1	URB-F2	URB-F3	URB-F4
Tide level 1.50m (ha)	7563	4297	5738	32427	1555	656	678	7915	971	383	263	485
Tide level 1.85m (ha)	9340	4199	8684	50016	2650	1476	1039	10804	976	627	782	2102

Fig. 4.15: Flooded areas of flooding frequency grades at the tide levels in urban zones of Ho Chi Minh City

For flooding frequency, data in the figure 4.15 shows that increase appears in the most of grades when tide level changes from 1.5m to 1.85m. Especially, there is a significant rise in the grade 3 and 4, with each of them develops nearly 1.5 times. In the each tidal level, almost the flooded areas are grade 4. This shows that flood impacts seriously. However, locations of these areas are forest and field lands. These regions are low land so that flooding frequency is more than the others are able to understand. In the residential areas, flooding frequency is almost grade 1. This is pointed out the people are not impacted too much on their living activities.

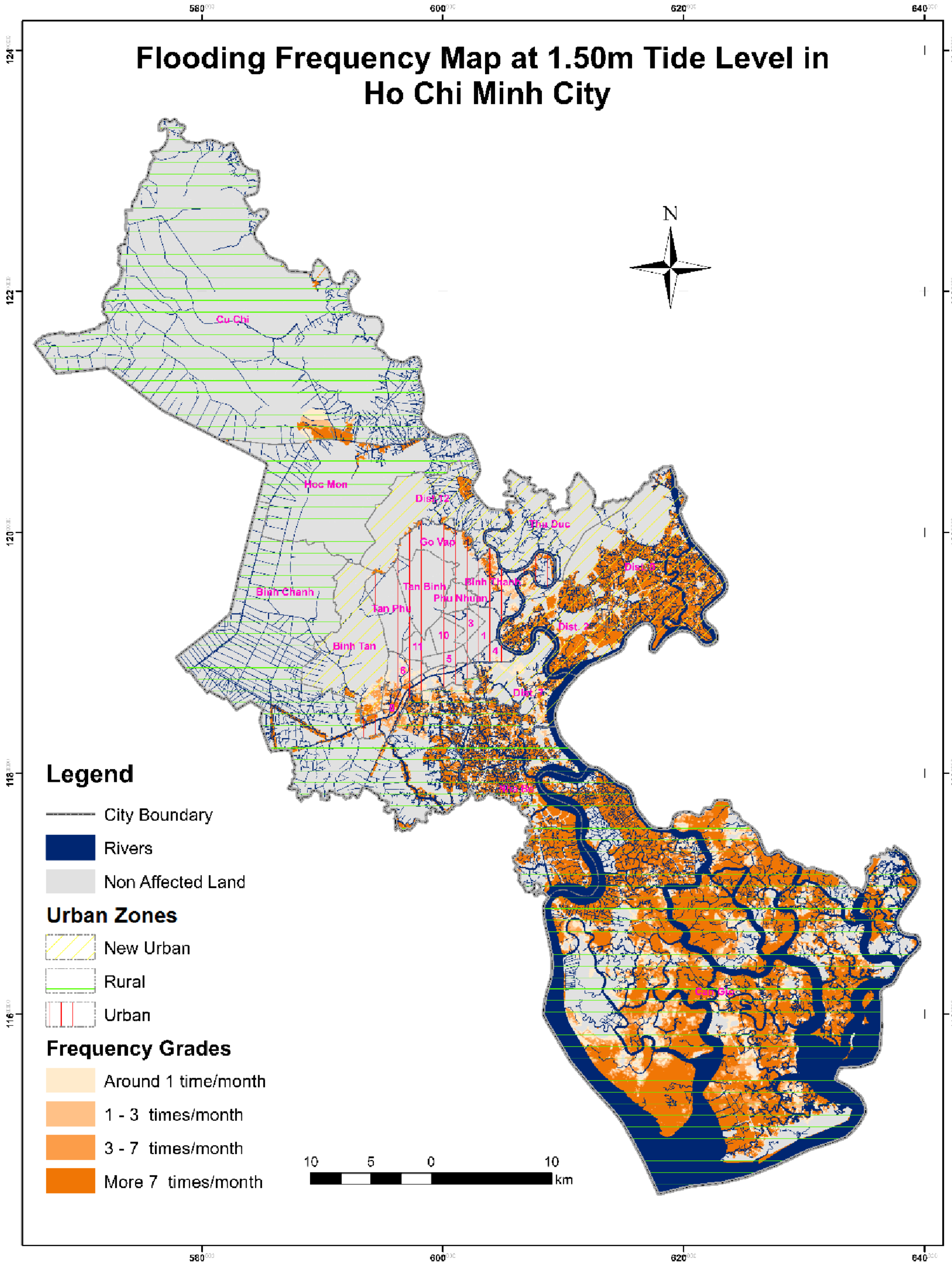


Fig. 4.16: Flooding frequency maps at 1.50m tide level in urban zones of Ho Chi Minh City

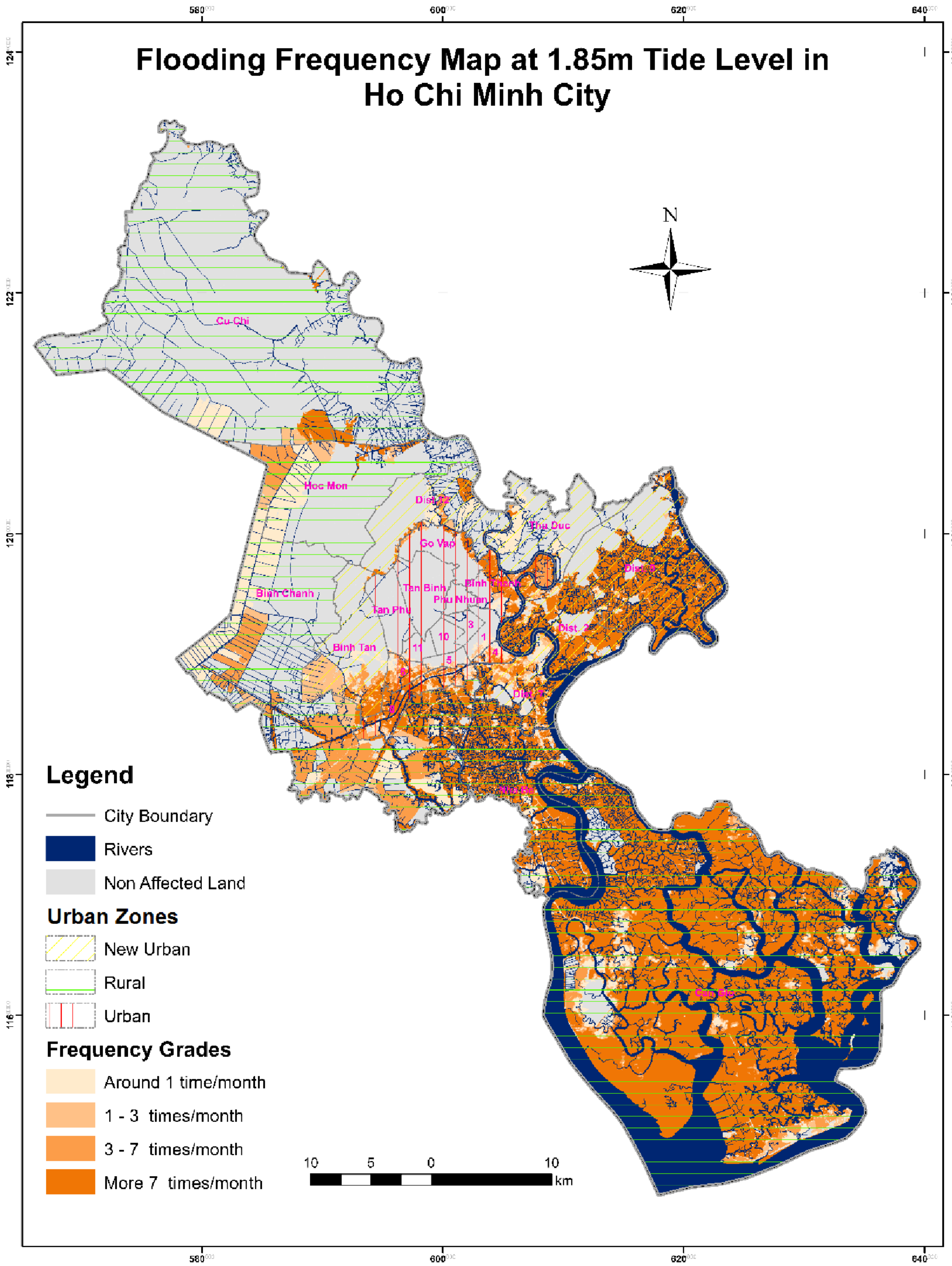


Fig. 4.17: Flooding frequency maps at 1.85m tide level in urban zones of Ho Chi Minh City

Chapter 5. Flood Risks of Houses

1. Introduction

Flooding affects to a lot of fields and flood impact can be divided some types such as direct and indirect impact or tangible and intangible value damage. Direct damage is the physical damage caused to buildings, transport… and their contents, whereas indirect damage represents the loss of industrial or business process. Tangible value losses represent those that can be allocated a monetary value, and intangible value losses are those to which it is impossible to allocate a monetary value (Proverbs & Soetanto, 2004). With applying GIS to evaluate impacts and risks caused by flood damage, the study will focus on the direct tangible losses.

The evaluation of a disaster or a hazard in consideration after all is impacts to the human aspects such as human life, health, properties, income, and living environment… in the interested regions. With a lot of those aspects that are able to assess, this research focuses to aspects that impact directly mostly inhabitants in the study area. In that analysis, the house objects are assessed by flood risk firstly. The houses are defined as the residential buildings that citizens live in. The houses influence mostly to inhabitant living and moreover they are environment to live human and protect them. Additionally, the houses are usually one of the highest value properties of inhabitants. Therefore, the assessment of flood risk for the houses is necessary.

The assessment of flood risk will be performed on the time scenarios in 2030 with the sea level rise in the highest scenario of climate change in Ho Chi Minh City as mentioned in the section 4.4 of the chapter 3. In the scenario, the maximum tide level is 1.85m and data of this scenario will be used to assess the flood risk for houses in the study area. The assessment of flood risk is conducted at two levels that are 1.85m and 1.50m. The first level is the maximum and the second is the most dangerous warning level at the current in Ho Chi Minh City at Phu An tidal station. Moreover, the second level is interested as the delegation of the level at the current time.

Additionally, risk analysis is the identification of the houses located in the areas affected by the flooding with the parameters of flood risk including: flooding duration, flooding depth and frequency of flooding. The houses that are considered to be at flooding risk are the houses exposed to flooded areas.

Moreover, to identify impact risk grades of the flooding characteristics for different regions, the assessment process is based on the flooding characteristics. Therefore, the research classifies Ho Chi Minh City to three urban zones. The first zone is called old center urban which includes the old city center and districts. The second zone is called new urban which includes the new districts that are separated from the old rural (PMVG, 1997; PMVG, 2003). And the last one is calls rural which the rest of Ho Chi Minh City is.

At the current there are some available researches also conducted impacts of the climate change to Ho Chi Minh City but the house object was not assessed (ADB, 2009a; ADB, 2009b; ADB, 2009c; WB, 2010). The reason of them can be difficult in the collecting of house data because of Vietnamese national regulation to publish the data and the data is not updated continuously. This is difficulty of the research as shown in the chapter 3 with the building data is not updated to the present time. However, to assess the flood risk to house objects that is helpful to generate a forecast data for beyond researches and make a warning to the local authority in the development plan of Ho Chi Minh City in the future. Consequently, this research uses house data in the best ability to collect at the current time that is in 2006 for flood risk assessment to houses.

2. Method

Generally, method of assessing the damage and affected by the flooding is based on spatial relationship with a spatial analysis tool set, a powerful tool set of GIS. The spatial analysis based on the correspondence between spatial data layers to consider spatial relationships between objects on those layers (DeMers, 2009; ESRI, 2004; Loi et al., 2008; Longley et al., 2005). For the assessment of flood risk in Ho Chi Minh City, the analysis of the spatial relationship between interested features and flooding maps will be done. From spatial relationship, the objects on the interested features located in the flooded areas will be determined and based on the characteristics of the flooding at that location the flood risk will be assessed qualitative or quantitative (Dutta, Herath and Musiake, 2003).

Particularly, method to apply for identification is considering the spatial relationship of the building layer and the flooding maps, buildings were flooded and not flooded will be determined. Similarly, using the characteristics of flooding such as depth, duration and frequency of the flood, the damage of the buildings in the flooded area will calculate a qualitative or quantitative assessment.

The inundated houses are calculated and assessed about areas for each of flood risk grades based on flood characteristics including flooding depth, duration and frequency. Approach of classification of the flood risk grades marches to that of the flood risk grades of characteristics that are described in the sections 6.3.2, 6.4.2 and 6.5.2 in the chapter 4. Exceptionally, with the flooding depth characteristic there is a new situation for inundated houses that is the houses located in the flooded areas but their ground floor is not below of the flood level so that no water flows into inner of the houses. To evaluate this situation, the research suggests one more flood risk grade called depth grade 0.

A summary for flood risk grades of houses is described as followings:

- Depth grade 0 (D0): This grade is called for only affected houses. In the grade, the houses are only located inside of the flooded areas but ground floor is not below of the flood level so that no water flows into inner of the houses.
- Depth grade 1 (D1): In the grade, the depth is above 0.0m and below 0.5m. This damages furniture and is the least dangerous to the human being there.
- Depth grade 2 (D2): In the grade, the depth is from 0.5m to below 1.2m. This is the grade that can be dangerous to children and elderly people and damages almost the properties inner houses.
- Depth grade 3 (D3): In the grade, the depth is from 1.2m to below 1.8m. This is the grade that does not only damage properties but also is dangerous to almost human living there.

- Depth grade 4 (D4): In the grade the depth is more 1.8m. Almost people can not living in this area if there is not any preparation for life conditions when flood appears.

3. Result and discussion

3.1. Affected areas

Data in the table 5.1, figure 5.1 and figure 5.2 shows an increasing flooded house area from the rural to the old center urban at all tide levels 1.50m and 1.85m. This can be to understand because the house density in Ho Chi Minh City is gradually high from the rural to the old center urban. At two tide levels, the flooded house area in the old center urban holds a major portion. When the tide levels rises the flooded house area in the old center urban is increased more than that of in the other zones do.

At the tide level 1.50m, the flooded house area accounts for 50% in the old center urban, 29% in the new urban and 21% in the rural. At the tide level 1.85m, the flooded house area has a little change with 45% in the old center urban, 32% in the new urban and 23% in the rural. The reason of this phenomenon is terrain in the old center urban is higher than the terrain in the new urban and the rural besides the new flooded areas are low land and protected by roads when tide level is 1.50m and the areas are inundated when tide level rises so that there are a lot of houses in these areas flooded. The new flooded areas are occupied in the new urban and the rural with a lot of large regions. Therefore there is increase the flooded house areas in the new urban and the rural more than in the old center urban.

Tab. 5.1: Affected house areas at the tide levels in urban zones of Ho Chi Minh City

No	Urban Zones	Code	Affected House Areas				Total House Areas (ha)
			TL 1.50m		TL 1.85m		
			ha	%	ha	%	
3	Old Center Urban	URB	755	50.4	1,577	44.9	2,667
2	New Urban	NUR	438	29.3	1,138	32.4	3,551
1	Rural	RUR	304	20.3	799	22.7	5,030
Total			1,498	100.0	3,515	100.0	11,248

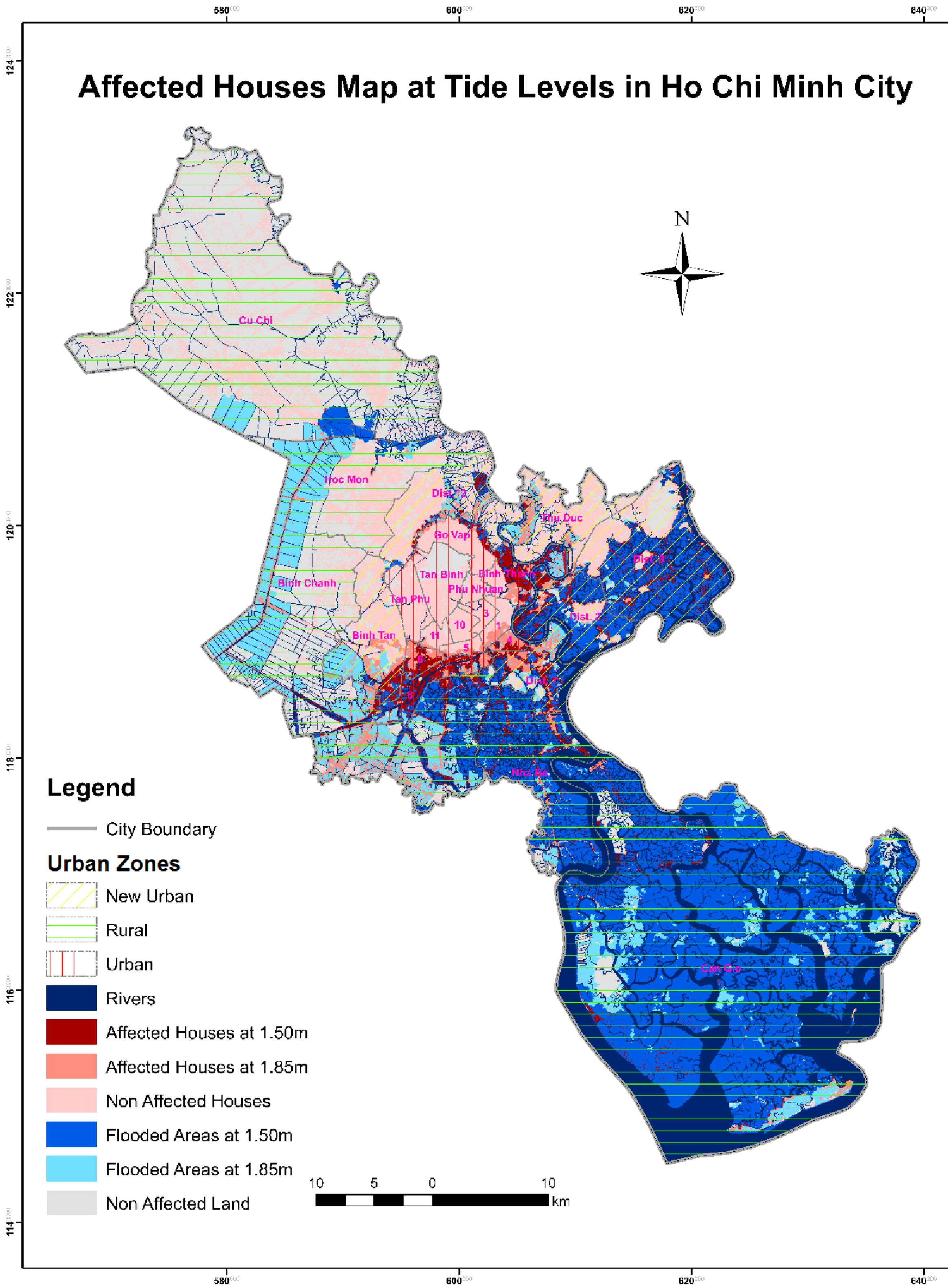
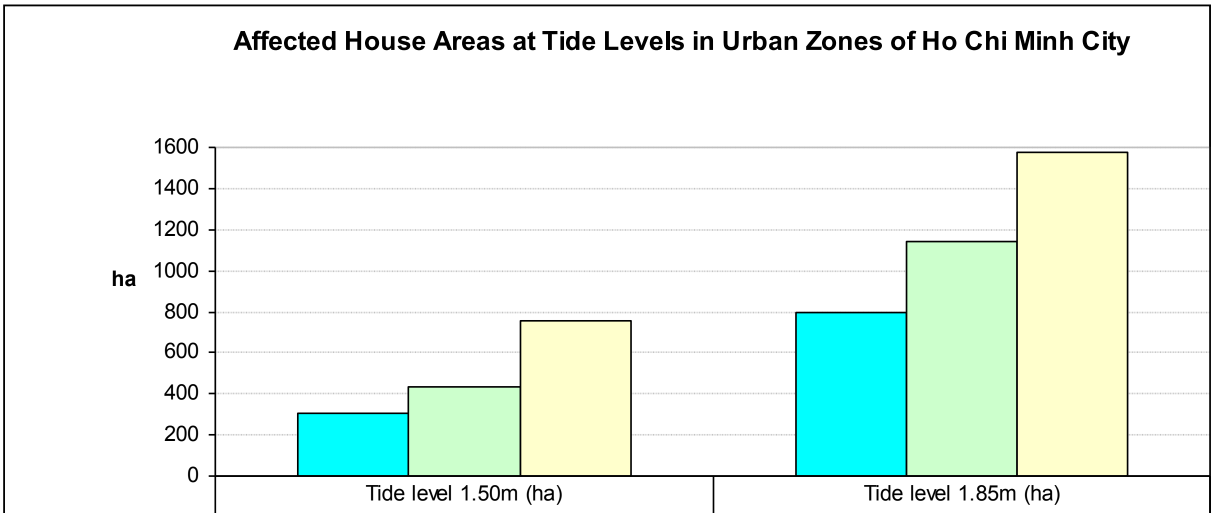


Fig. 5.1: Affected houses map at the tide levels in Ho Chi Minh City

The flooded areas of houses are changed much when tidal level varies. At the tide level 1.5m flooded areas of houses are about one and half thousand hectares and at the tide level 1.85m, the flooded house areas are raised more 2.3 times with 3.5 thousand hectares. This confirms that flood impacts so much to residential living activities.



	Tide level 1.50m (ha)	Tide level 1.85m (ha)
Rural	304	799
New Urban	438	1138
Old Center Uraban	755	1577

Fig. 5.2: Affected house areas at the tide levels in urban zones of Ho Chi Minh City

Moreover this also shows that new urban areas of residential development are low land and will be affected a lot in the future by high tide. However, there is different increase for each of the urban zones. Strongly increase is the rural with 2.6 times and the new urban with 2.5 times and the least increase is the old center urban with 2 times. The reason for the increase is houses in the rural and new urban are constructed in the low lands and protected by roads. And when tide level reaches 1.85m the roads can not help the houses prevent flood therefore flooded houses areas in these zones will be increased.

3.2. Depth grades

For the flooded houses, the flooding depth has five grades. The grades include four grades from flooding depth map and one grade is added grade for the situation of houses located inside the flooded areas but the water is not flow into the houses. The added grade is called grade 0. As data in the table 5.2 and chart in the figure 5.3, there is reduce gradually the flooded house area at high grades of flooding depth at two tide levels. However, there are differences of weight for each of the grades each of tide levels.

Tab. 5.2: Affected house areas of flooding depth grades at the tide levels in Ho Chi Minh City

No	Depth	Code	Affected House Areas			
			TL 1.5m		TL 1.85m	
			ha	%	ha	%
1	Only affected	D0	1,286	85.9	1,931	54.9
2	0 -0.5m	D1	206	13.7	1,418	40.3
3	0.5 - 1.2m	D2	6	0.4	165	4.7
4	1.2 -1.8m	D3	0	0.0	1	0.0
Total			1,498	100.0	3,515	100.0

At the tide level 1.50m, almost flooded house area is grade 0 with 85.6% and grade 1 with 13.7% and the rest of that is grade 2. This is natural phenomenon because inhabitants can only live in the houses which are flooded a low depth grade or only affected grade otherwise they can not do anything for their life. This shows that the residents living there are not really impacted so much dangerous to physical body but they can be effected to mental and a little properties.

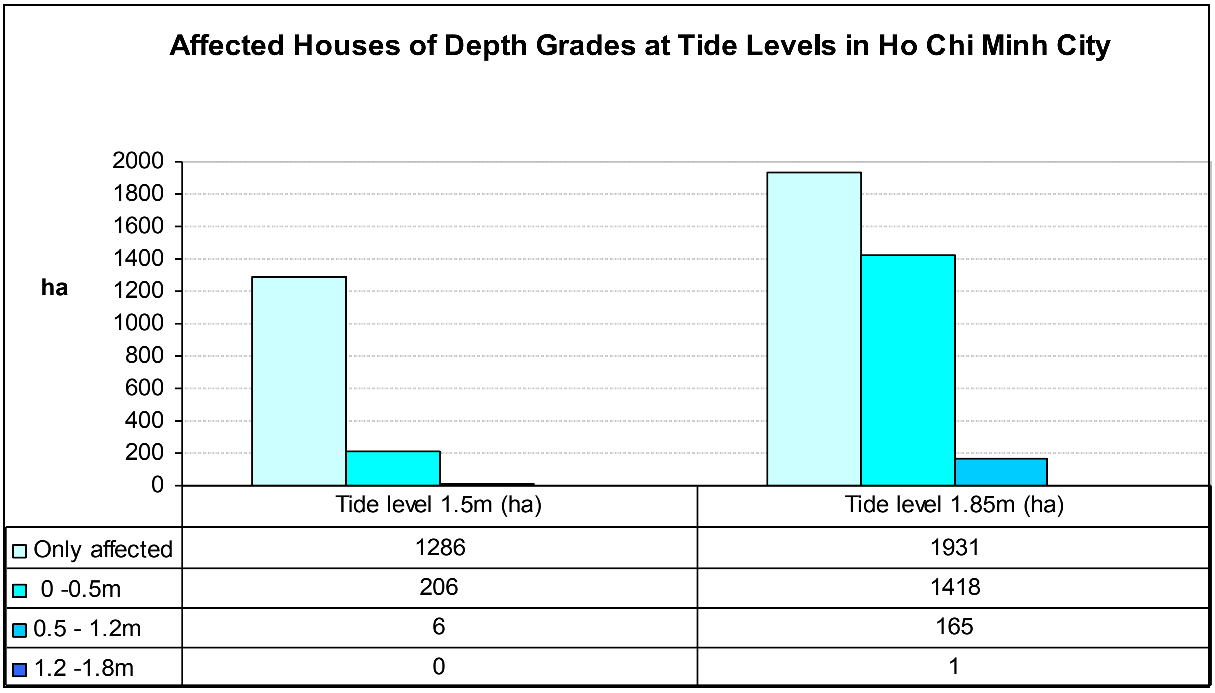


Fig. 5.3: Affected house areas of flooding depth grades at the tide levels in Ho Chi Minh City

A notice in the result is there is a small area of flooded houses with grade 2 in the rural and new urban as shown in the table 5.3 and figure 5.4. This may be errors of the interpolation method of house foundations when the houses are located in the special zones such as location near rivers and the houses have special characteristics but the research has not gotten elevation information enough.

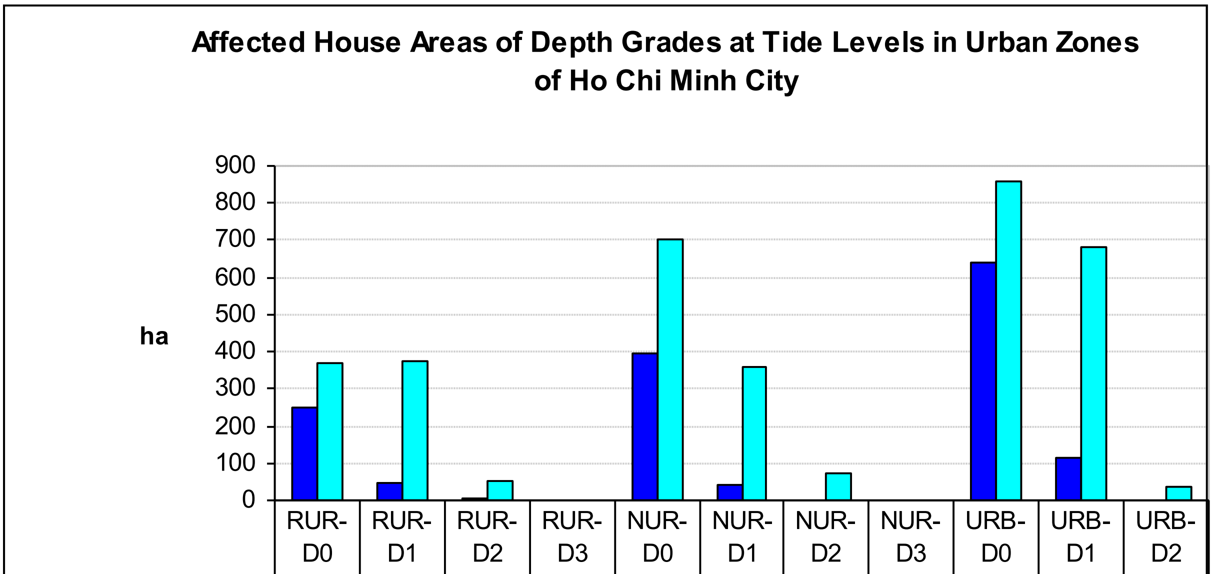
At the tide level 1.85m, flooded house area at all the grades of flooding depth is increased with different amount so that there is a change of percentage for the flooding depth grades compared with tide level 1.50m. The flooded house area at the grade 0 still holds the most with 55% and then is grade 1 with 40% and the third is grade 2 with 4.7% and the least is grade 3 with 0.3%. The flooded house areas increase at the grade 1 significant. The cause of this a lot of flooded house areas from grade 0 at the tide level 1.5m transfers to grade 1 at this tide level. This shows that the flooded houses of the grade 0 at tide level 1.5m have ground floor elevation not much higher than the tide level.

Tab. 5.3: Affected house areas of flooding depth grades at the tide levels in urban zones of Ho Chi Minh City

No	Urban Zones	Depth	Code	Affected House Areas			
				TL 1.50m		TL 1.85m	
				ha	%	ha	%
1	Rural	Only affected	RUR-D0	251.5	16.8	370.4	10.5
2	Rural	0 -0.5m	RUR-D1	49.4	3.3	374.3	10.7
3	Rural	0.5 - 1.2m	RUR-D2	3.4	0.2	54.4	1.5
4	Rural	1.2 -1.8m	RUR-D3	0.0	0.0	0.2	0.0
5	New Urban	Only affected	NUR-D0	393.2	26.3	703.6	20.0
6	New Urban	0 -0.5m	NUR-D1	42.7	2.9	360.2	10.2
7	New Urban	0.5 - 1.2m	NUR-D2	2.1	0.1	73.3	2.1
8	New Urban	1.2 -1.8m	NUR-D3	0.0	0.0	1.2	0.0
9	Old Center Urban	Only affected	URB-D0	641.6	42.8	856.5	24.4
10	Old Center Urban	0 -0.5m	URB-D1	113.5	7.6	683.3	19.4
11	Old Center Urban	0.5 - 1.2m	URB-D2	0.0	0.0	37.5	1.1
Total				1,497.5	100.0	3,515.0	100.0

Additionally, the new flooded houses are located at the low land and protected by streets whose elevation is not so much higher than 1.5m. At the tide level 1.85m the flooded house areas are also concentrated in the grade 0 and 1 and dominating more than 95%. A warning is the flooded house area appears at the grade 3. This shows that dangerousness to human at tide level 1.85m can be serious.

The data in the table 5.3 and chart of figure 5.4 shows more clearly about change and distribution of flooding depth grades in the urban zones. At the tide level 1.50m in all urban zones there is the flooded house area at the grade 0 and grade 1 but there is a small flooded house area at the grade 2 in the rural and new urban. The reason can be errors of the interpolation method for foundation elevation of the houses. The most attention is the flooded house area is increased in all urban zones at the tide level 1.85m.



	RUR-D0	RUR-D1	RUR-D2	RUR-D3	NUR-D0	NUR-D1	NUR-D2	NUR-D3	URB-D0	URB-D1	URB-D2
Tide level 1.50m (ha)	251.5	49.4	3.4	0.0	393.2	42.7	2.1	0.0	641.6	113.5	0.0
Tide level 1.85m (ha)	370.4	374.3	54.4	0.2	703.6	360.2	73.3	1.2	856.5	683.3	37.5

Fig. 5.4: Affected house areas of flooding depth grades at the tide levels in urban zones of Ho Chi Minh City

Moreover there are new grades in all urban zones. In the rural and new urban grade 3 is appeared and the old center urban occurs grade 2. The flooded house area is increased very much at the grade 1and the flooded house area at this grade holds also the major portion at the tide level 1.85m. The cause of the phenomenon is there is much low land regions in all urban zones such as Thu Duc District, District 2, District

7, District 9 and Binh Tan District in the new urban zone, Binh Chanh Rural District in the rural zone and Binh Thanh District, District 4, District 6 and District 8 in the old center urban in which are protected by roads at tide level 1.50m.

3.3. Duration grades

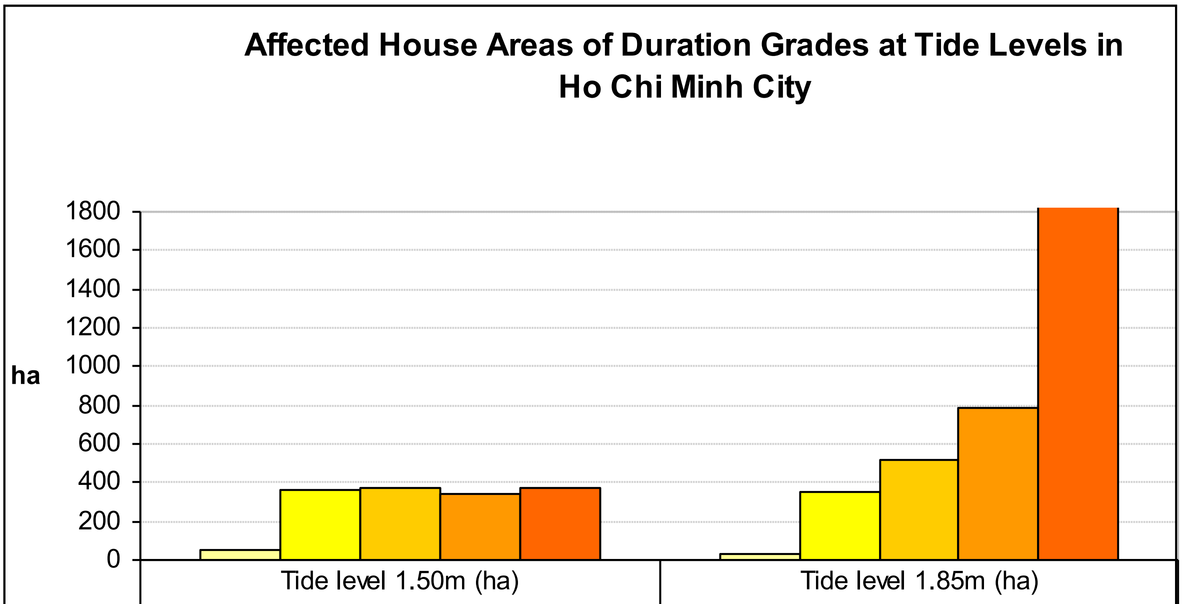
The distribution of the flooded house area at all the flooding duration grades is shown in table 5.4 and chart figure 5.5.

At the tide level 1.50m almost the flooded house area is concentrated at four the highest grades with the same percentage and at the grade 1 that holds a small percentage. This shows that the flooded houses of duration are long. There are two reasons for explanation of the phenomenon. The first is tide characteristic as tide value range for the grade 1 is very short with difference between high boundary and low boundary values 1cm (see appendix A.1). As a result, probability of the land is flooded at the grade 1 is very small. The second is only the high regions are flooded to be classified to the grade 1. But there is not much high land in Ho Chi Minh City therefore the flooded house area at the grade 1 is not much.

Tab. 5.4: Affected house areas of flooding duration grades at the tide levels in Ho Chi Minh City

No	Duration	Code	Affected House Areas			
			TL 1.50m		TL 1.85m	
			ha	%	ha	%
1	Less 1h	T1	51	3.4	30	0.9
2	1 - 2h	T2	363	24.2	348	9.9
3	2 - 3h	T3	376	25.1	515	14.7
4	3 - 4h	T4	338	22.5	791	22.5
5	More 4h	T5	371	24.8	1,831	52.1
Total			1,498	100.0	3,515	100.0

At the tide level 1.85m, increasing flooded house area is extended much more at the grades. Besides two reasons that are described above there is one more reason for this tide level. As shown in the appendix A.1, the flooded house area at all grades at tide level 1.50m is moved to the grade 5 at tide level 1.85m so that the flooded house area at the grade 5 holds on more than the others. Moreover, the new flooded areas at tide level 1.85m are low land regions and protected by road when tide level 1.50m but the road elevations are not so much more than tide level 1.50m so that a lot of the flooded areas is inundated at the grade 5 and the houses located in these areas are the same situation of flooding duration. And result is flooded house area at the grade 5 holds on 52%. This shows that the dangerousness needs to be warned when tide level rises in the future.



	Tide level 1.50m (ha)	Tide level 1.85m (ha)
Less 1h	51	30
1 - 2h	363	348
2 - 3h	376	515
3 - 4h	338	791
More 4h	371	1831

Fig. 5.5: Affected house areas of flooding duration grades at the tide levels in Ho Chi Minh City

To analyze insight about the distribution of the flooded house area in the urban zones, the information in table 5.5 and chart figure 5.6 shows for that.

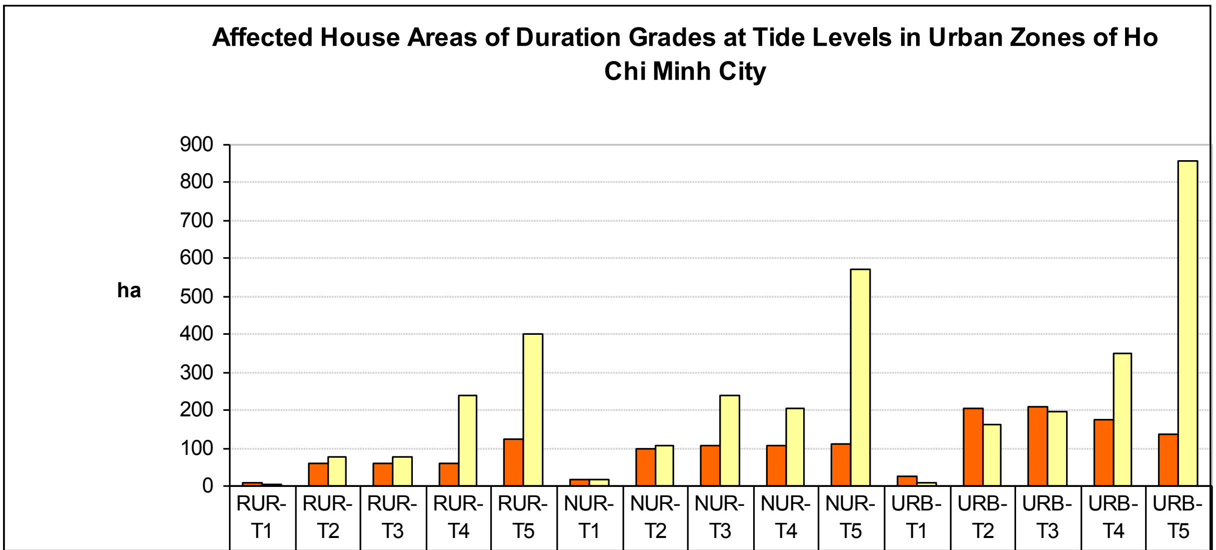
In the rural, the flooded house area concentrates a major portion at the grade 5 and the least at the grade 1 at two tide levels. The reason is the rural is low land regions so that almost houses in the regions are flooded long duration. In the rural at the tide level 1.85m there is increasing flooded house area at the grade 5 because the new flooded areas in Binh Chanh Rural District are low land regions but they are protected by road as tide level 1.50m however the road elevations are not much higher than tide level

1.50m and as a result when tide level rises the flooded areas are at grade 5 of flooding duration.

Tab. 5.5: Affected house areas of flooding duration grades at the tide levels in urban zones of Ho Chi Minh City

No	Urban Zones	Duration	Code	Affected House Areas			
				TL 1.50m		TL 1.85m	
				ha	%	ha	%
1	Rural	Less 1h	RUR-T1	7	0.4	3	0.1
2	Rural	1 - 2h	RUR-T2	58	3.9	76	2.2
3	Rural	2 - 3h	RUR-T3	59	4.0	78	2.2
4	Rural	3 - 4h	RUR-T4	59	3.9	239	6.8
5	Rural	More 4h	RUR-T5	122	8.1	403	11.5
6	New Urban	Less 1h	NUR-T1	18	1.2	17	0.5
7	New Urban	1 - 2h	NUR-T2	98	6.6	108	3.1
8	New Urban	2 - 3h	NUR-T3	107	7.2	240	6.8
9	New Urban	3 - 4h	NUR-T4	105	7.0	203	5.8
10	New Urban	More 4h	NUR-T5	110	7.4	570	16.2
11	Old Center Urban	Less 1h	URB-T1	26	1.7	10	0.3
12	Old Center Urban	1 - 2h	URB-T2	207	13.8	164	4.7
13	Old Center Urban	2 - 3h	URB-T3	209	14.0	197	5.6
14	Old Center Urban	3 - 4h	URB-T4	174	11.6	348	9.9
15	Old Center Urban	More 4h	URB-T5	139	9.3	859	24.4
Total				1,498	100.0	3,515	100.0

In the new urban, the situation is similar to the rural however there is difference of percentages for the grades. At the tide level 1.50m the flooded house area at the grade 1 is the least and the other grades are almost similar with the same percentage. This shows that distribution of flooded houses in the regions in which slope is gradually changed. Moreover number of houses located in very low land regions is not as much as that is the rural regions. At the tide level 1.85m there is strongly increasing flooded house area at the grade 5. This shows that the roads help very much to protect the houses in the low land regions at tide level 1.50m but they can not do at tide level 1.85m. And additionally, this also shows that the road elevations are not much higher than tide level 1.50m and as a result the houses protected by the roads are very vulnerable when tide level rises.



	RUR-T1	RUR-T2	RUR-T3	RUR-T4	RUR-T5	NUR-T1	NUR-T2	NUR-T3	NUR-T4	NUR-T5	URB-T1	URB-T2	URB-T3	URB-T4	URB-T5
Tide level 1.50m (ha)	7	58	59	59	122	18	98	107	105	110	26	207	209	174	139
Tide level 1.85m (ha)	3	76	78	239	403	17	108	240	203	570	10	164	197	348	859

Fig. 5.6: Affected house areas of flooding duration grades at the tide levels in urban zones of Ho Chi Minh City

In the old center urban, at the tide level 1.50m the flooded house area concentrates a major portion at the grade 2 and grade 3 and that reduces at the grade 4 and grade 5. The cause of the phenomenon is because high land regions in the old center urban occupy almost and the low land regions are protected by roads. However, when tide level rises to 1.85m vulnerability to these houses is exposed with increasing of flooded house area at grade 4 and grade 5 is extremely high. The flooded house area at the grade 1, grade 2 and grade 3 is reduced. The reason may be movement of the flooded house area of these grades at tide level 1.50m to the grade 4 and grade 5 at the tide level 1.85m. Additionally, increasing of new flooded houses in the high land regions is not as much as in the low land regions of Binh Thanh District, District 4, District 6 and District 8. These regions at tide level 1.50m are controlled by the roads to protect them for preventing inundation.

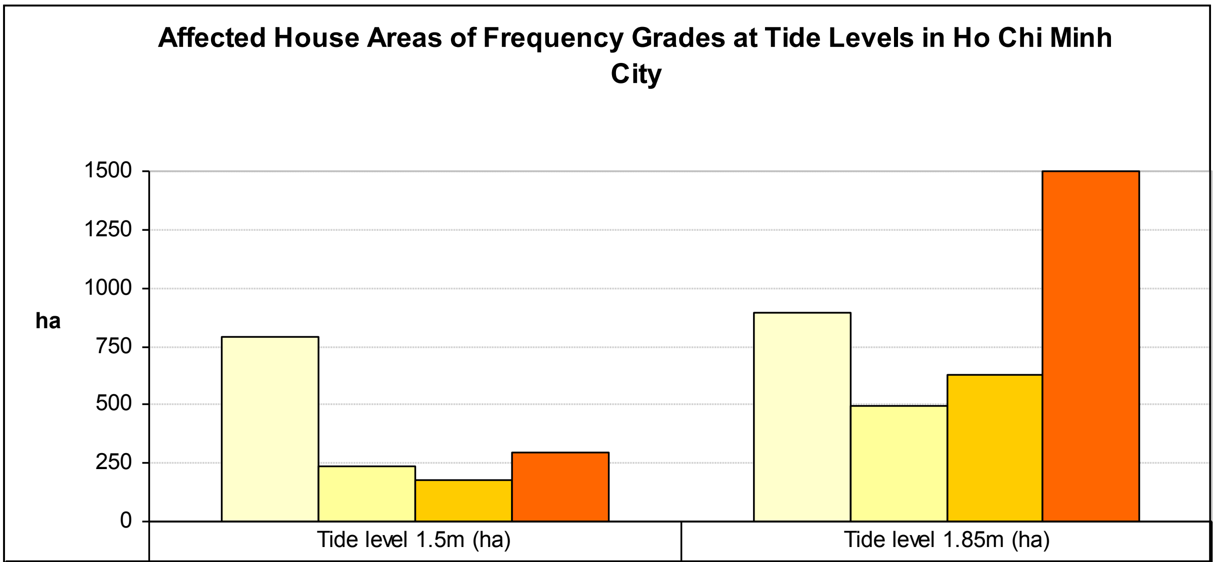
3.4. Frequency grades

From data in table 5.6 and chart in figure 5.7, some conclusions are found. At the tide level 1.50m the flooded house area is the most with 53% at the grade 1 and that is the least with 11% at grade 3, with 16% at the grade 2 and with 20% at the grade 4. This is because house density reduces gradually from high land to low land in Ho Chi Minh City. Moreover, because tide level value ranges matching with the flooding frequency grades are not the same as each of others as shown in appendix A.2. In the appendix, the tide value range matching with flooding frequency grade 1 is large that of grade 2 and grade 3 so that the flooded house areas at the grade 2 and grade 3 are very little. But why is the flooded house area at the grade 4 also little?

Tab. 5.6: Affected house areas of flooding frequency grades at the tide levels in Ho Chi Minh City

No	Frequency	Code	Affected House Areas			
			TL 1.5m		TL 1.85m	
			ha	%	ha	%
1	Less 1 t/m	F1	789	52.7	893	25.4
2	1 - 3 t/m	F2	240	16.0	494	14.0
3	3 - 7 t/m	F3	174	11.6	631	17.9
4	More 7 t/m	F4	295	19.7	1,498	42.6
Total			1,498	100.0	3,515	100.0

The cause of the phenomenon is the inhabitants do not like to build houses in the very low land regions and the low land regions where can build houses are protected by roads to prevent inundation. This reason is shown clearly when tide level rises to 1.85m. At the high tide level, although the flooded house area at all flooding frequency grades is increased if that is compared with tide level 1.50m, increase the flooded house area at the grade 2 is 2.1 times, at the grade 3 is 3.6 times and the most at grade 4 is 5.1 times as many as that of at tide level 1.50m. This shows that there are a lot of houses in the new flooded areas and the elevations of the areas are much lower than tide level 1.85m and they are inundated because the protecting roads can not help to prevent flood at high tide level. As a result at the tide level 1.85m the houses are covered by water with longer time, much deeper and more frequent appearance.



	Tide level 1.5m (ha)	Tide level 1.85m (ha)
Less 1 t/m	789	893
1 - 3 t/m	240	494
3 - 7 t/m	174	631
More 7 t/m	295	1498

Fig. 5.7: Affected house areas of flooding frequency grades at the tide levels in Ho Chi Minh City

To see more clearly impacts of flooding frequency grades to the houses in the urban zones, the data in table 5.7 and chart in figure 5.8 is very meaningful.

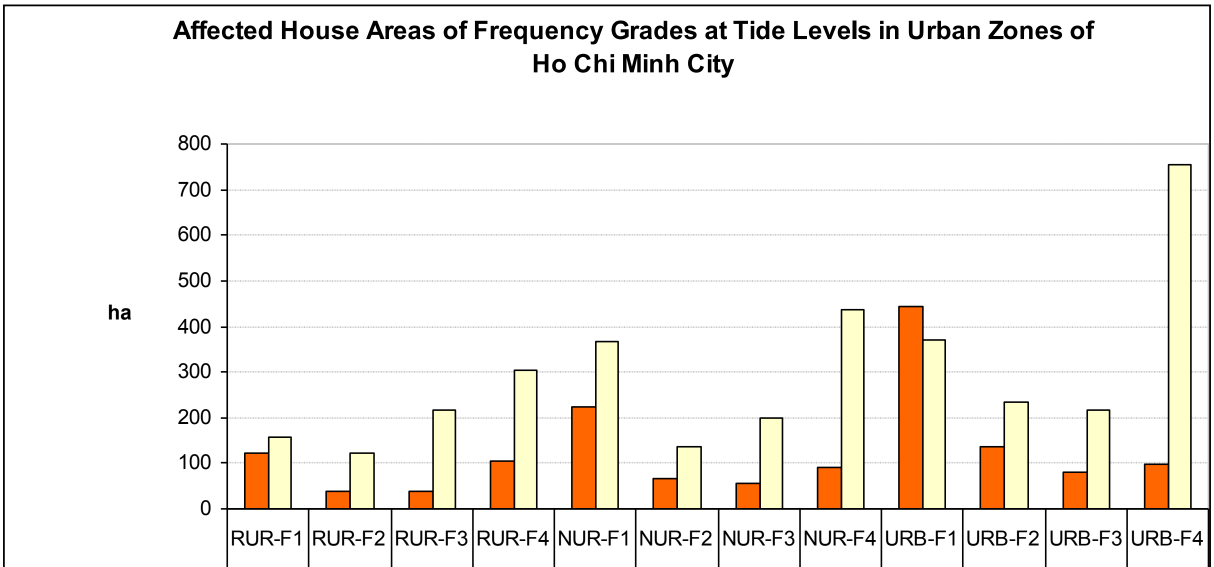
In the rural, at the tide level 1.50m almost the flooded house area concentrates at the grade 1 and grade 4. The area concentrates much at the grade 1 is because the tide value range matching with flooding frequency grade 1 is large that of grade 2 and grade 3 so that probability of flooded regions classified in the grade 1 is more the others. The area concentrates at the grade 4 is because in the rural almost area is low land so that there are a lot regions where are inundated very easily. At the tide level 1.85m there is strong increase of the flooded house area at the grade 2 and grade 3. The reason is the new flooded area in Binh Chanh Rural District is low land regions and they are protected by roads but the road elevations are not much higher than tide level 1.50m so that when tide level rises these regions are inundated at the grade 2 and grade 3.

Tab. 5.7: Affected house areas of flooding frequency grades at the tide levels in urban zones of Ho Chi Minh City

No	Urban Zones	Frequency	Code	Affected House Areas			
				TL 1.50m		TL 1.85m	
				ha	%	ha	%
1	Rural	Less 1 t/m	RUR-F1	124	8.3	158	4.5
2	Rural	1 - 3 t/m	RUR-F2	38	2.5	122	3.5
3	Rural	3 - 7 t/m	RUR-F3	37	2.5	215	6.1
4	Rural	More 7 t/m	RUR-F4	105	7.0	304	8.7
5	New Urban	Less 1 t/m	NUR-F1	223	14.9	365	10.4
6	New Urban	1 - 3 t/m	NUR-F2	67	4.5	137	3.9
7	New Urban	3 - 7 t/m	NUR-F3	56	3.7	198	5.6
8	New Urban	More 7 t/m	NUR-F4	92	6.1	438	12.5
9	Old Center Urban	Less 1 t/m	URB-F1	442	29.5	370	10.5
10	Old Center Urban	1 - 3 t/m	URB-F2	135	9.0	235	6.7
11	Old Center Urban	3 - 7 t/m	URB-F3	81	5.4	217	6.2
12	Old Center Urban	More 7 t/m	URB-F4	97	6.5	755	21.5
Total				1,498	100.0	3,515	100.0

In the new urban there are some differences of percentage of the flooded area at the grades compared with the rural. At the tide level 1.50m the flooded house area at the grade 1 is remarkable and the other grades are almost similar with the same percentage. Besides the reason of classification for flooding frequency characteristic with the tide value range matching with flooding frequency grade 1 is large that of grade 2 and grade 3 the other cause is distribution of flooded houses in the regions in which slope is gradually changed. Moreover number of houses located in very low land regions is not as much as that is the rural regions. At the tide level 1.85m there is strongly increasing flooded house area at all grades. However, the most of the flooded house area is extended at the grade 4 This shows that the roads help very much to protect the houses in the low land regions at tide level 1.50m but they can not do at tide level 1.85m. And additionally, this also shows that the road elevations are not much higher than tide level 1.50m and as a result the houses protected by the roads are very vulnerable when tide level rises.

In the old center urban, at the tide level 1.50m the flooded house area concentrates a major portion at the grade 1 and grade 2 and that reduces gradually at the grade 3 and grade 4. Besides the reason of classification for flooding frequency characteristic with the tide value range matching with flooding frequency grade 1 is large that of grade 2 and grade 3, the cause of the phenomenon is because high land regions in the old center urban occupy almost and the low land regions are protected by roads. However, when tide level rises to 1.85m vulnerability to these houses is exposed with increasing of flooded house area at grade 4 is extremely high.



	RUR-F1	RUR-F2	RUR-F3	RUR-F4	NUR-F1	NUR-F2	NUR-F3	NUR-F4	URB-F1	URB-F2	URB-F3	URB-F4
Tide level 1.50m (ha)	124	38	37	105	223	67	56	92	442	135	81	97
Tide level 1.85m (ha)	158	122	215	304	365	137	198	438	370	235	217	755

Fig. 5.8: Affected house areas of flooding frequency grades at the tide levels in urban zones of Ho Chi Minh City

Additionally, increasing of new flooded houses in the high land regions is not as much as in the low land regions of Binh Thanh District, District 4, District 6 and District 8. These regions at tide level 1.50m are controlled by the roads along canals to protect them for preventing inundation.

Chapter 6. Flood Risk of Population

1. Introduction

As mention in the chapter 5, assessment of the flood risk is classed to tangible, intangible, direct and indirect damages (Proverbs & Soetanto, 2004). But with applying GIS to evaluate impacts and risks caused by flood damage, the study will focus on the direct tangible losses.

With the analysis of the important aspects to the human, continuously the assessment of the flood risk comes identifying quantitative and qualitative of population in the study area. This is the most essential in the research because inhabitant is host of the society and subject of any activities. However, assessment method is based on GIS so that population impacted by flood risk needs to be based on one of the spatial objects that relate to inhabitant. In the research the spatial objects are houses therefore the houses are evaluated firstly and the population is calculated later on.

Similarly in the chapter 5, the assessment of flood risk to population will be performed on the time scenarios in 2030 with the sea level rise in the highest scenario of climate change in Ho Chi Minh City as mentioned in the section 4.4 of the chapter 3. In the scenario, the maximum tide level is 1.85m and data of this scenario will be used to assess the flood risk for houses in the study area. The assessment of flood risk is conducted at two levels that are 1.85m and 1.50m. The first level is the maximum and the second is the most dangerous warning level at the current in Ho Chi Minh City at Phu An tidal station. Moreover, the second level is interested as the delegation of the level at the current time.

Risk analysis is the identification of the number of population located in the areas affected by the flooding with the parameters of flood risk including: flooding duration, flooding depth and frequency of flooding. The number of the population that is considered to be at flooding risk is the inhabitant exposed to flooded areas.

Similarly to the houses, identifying impact grades of the flood characteristics to population for different regions, the assessment process is based on the flooding characteristics. Therefore, the research classifies Ho Chi Minh City to three urban zones (PMVG, 1997; PMVG, 2003). The first zone is called old center urban which includes the old city center and districts. The second zone is called new urban which includes the new districts that are separated from the old rural. And the last one is calls rural which the rest of Ho Chi Minh City is.

2. Method

Analysis of the number of people affected is a problem because of movement of human and so that the precision and methods somehow to proceed are often more resources and time costs. Human are not the ground objects so that the assessment can only be relative, forecast even if applying traditional methods which are the actual investigation. The cause of these is because of the constantly changing and often of residents in the study area.

For GIS, measuring number of living creatures is usually based on the spatial regions where the creatures are settling. Like wisely to define amount of affected people by flood needs to calculate quantification of spatial zones where residents are locating is flooded. Then based on the affected area of the spatial zones will determine the number of flood affected people from density value at the administrative level such as district, commune or city. The spatial zones for inhabitants living are usually used administration units (ADB, 2009a; ADB, 2009b; ADB, 2009c; WB, 2010) such as communes, districts… or areas of residential land use type or areas of houses (Maantay et al., 2010; Nhat, 2011). With three types of the spatial zones to calculate the population living on there, the spatial zones are the areas of the houses are the best accuracy because theoretically, these areas are the most fixing and suiting with the inhabitants living. In this study, population is data collected in 2009 but the houses data is captured 2006 therefore there are a conflict within time but the data is the general problem in the research. But theoretically approach based on the areas of houses is the best and in the research, the spatial zones are the areas of the houses are still selected.

The population data is enclosed in the commune administration. Therefore, to calculate the affected number of inhabitants the first step is computation of the density of inhabitant per house area for each commune. The second step is determined the affected house areas. And the final is calculation of the number of the affected inhabitants from each of the communes. Additionally, affected residents is also evaluated by using the characteristics of flooding such as depth, duration and frequency of the flood, the risk grades of the people in the flooded area will calculate a qualitative or quantitative assessment.

Because flood risk assessment to population is matched by the affected houses therefore grades of the flood risk assessment is the same as the houses. The affected population will also be evaluated the flood risk grades based on the flood characteristics including flooded area, depth, duration and frequency that are described in the sections 6.3.2, 6.4.2 and 6.5.2 in the chapter 4. With depth graded of flood risk, they are the same as the houses so that the depth grades will have one more grade 0 that is described in chapter 5. It means there is a flood risk grade of depth called depth grade 0 for the residents living in the flooded areas but their houses are not really occupied water inner.

3. Results and discussion

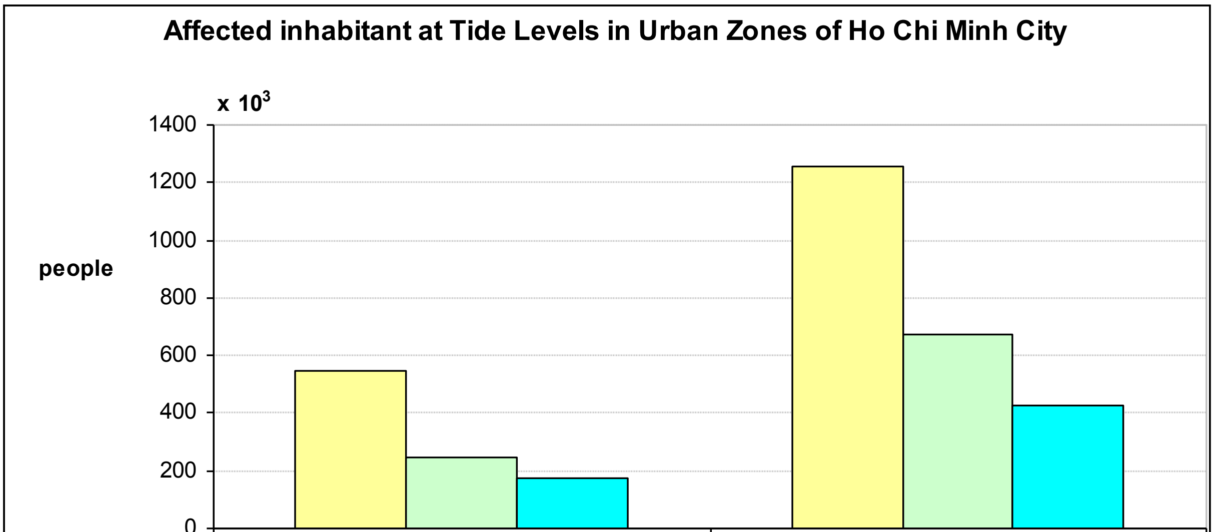
3.1. Affected population

Data in the table 6.1 and figure 6.1 shows an increase of flooded inhabitants from the rural to the old center urban at all tide levels 1.50m and 1.85m. This can be to understand because the population density in Ho Chi Minh City is gradually high from the rural to the old center urban. At two tide levels, amount of the flooded inhabitants in the old center urban holds a major portion. When the tide levels rises the flooded house area in the old center urban is increased more than that of in the other zones do.

Tab. 6.1: Affected inhabitant at the tide levels in urban zones of Ho Chi Minh City

No	Urban Zones	Code	Affected Inhabitant				Total Inhabitants (people)
			TL 1.50m		TL 1.85m		
			People	%	People	%	
1	Old Center Urban	URB	545,183	56.2	1,253,194	53.3	3,781,885
2	New Urban	NUR	247,555	25.5	673,979	28.7	2,059,703
3	Rural	RUR	177,176	18.3	424,053	18.0	1,281,622
Total			969,914	100.0	2,351,226	100.0	7,123,210

At the tide level 1.50m, amount of the flooded inhabitants accounts for 56% in the old center urban, 26% in the new urban and 18% in the rural. At the tide level 1.85m, amount of the flooded inhabitants has a little change with 53% in the old center urban, 29% in the new urban and 18% in the rural. The reason of this phenomenon is terrain in the old center urban is higher than the terrain in the new urban and the rural besides the new flooded areas are low land and protected by roads when tide level is 1.50m but the inhabitants living in the areas are affected when tide level rises so that there are a lot of affected inhabitants living in these areas flooded. The new flooded areas are occupied in the new urban and the rural with a lot of large regions. However, amount of the flooded inhabitants is only increased in the new urban because the population density in the rural is very low so that amount of the flooded inhabitants increases but that is not so much as the amount of the flooded inhabitants in the new urban does.



	Tide level 1.50m (ha)	Tide level 1.85m (ha)
Old Center Urban	545183	1253194
New Urban	247555	673979
Rural	177176	424053

Fig. 6.1: Affected inhabitant at the tide levels in urban zones of Ho Chi Minh City

The flooded areas of houses are changed much when tidal level varies. At the tide level 1.5m the affected inhabitants are nearly 1 million and at the tide level 1.85m, the affected inhabitants are raised more 2.4 times with more 2.35 million. This is reflected in the new flooded areas at tide level 1.85m is maintaining a lot of residents. However, for each of the urban zones there are differences of increase. The most increasing is the new urban 2.7 times, less is the rural 2.4 times and the least is the old center urban 2.3 times as many as flooded inhabitants at tide level 1.50m. The affected inhabitants are calculated based on the flooded house area but due to differences of population density in the urban zones so that number of the affected inhabitants in the urban zones is not quite similar to the flooded house area as the information shows in the rural and the old center urban. The rural has flooded house area increases much more than the old center urban does but the affected inhabitants are not really increased much more than the old center urban does.

3.2. Depth grades

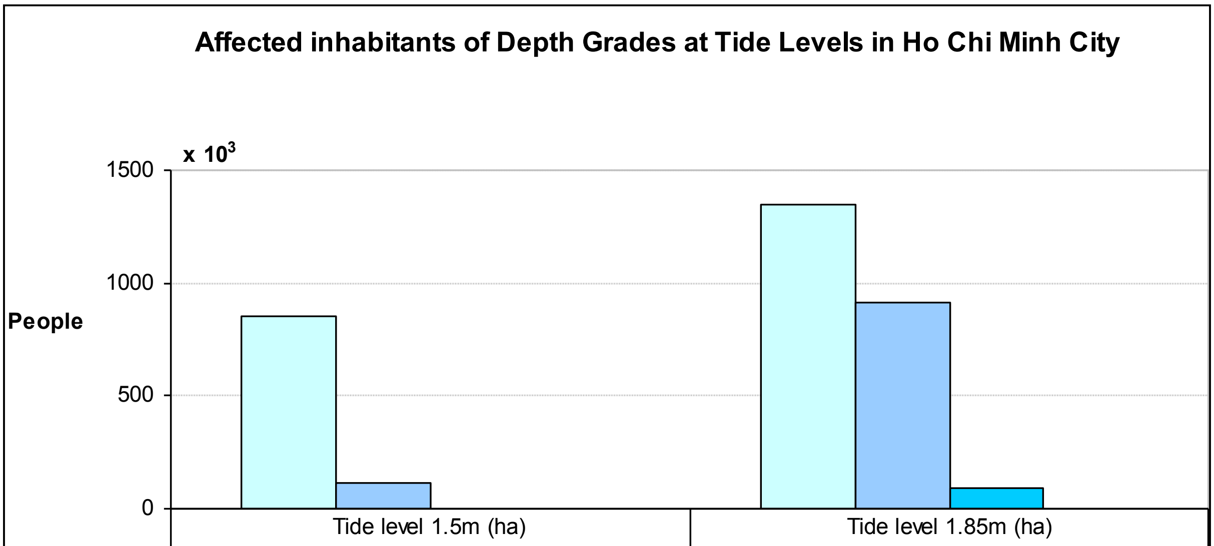
Similarly to the flooded houses, the flooding depth of inhabitants has five grades. The grades include four grades from flooding depth map and one grade is added grade for the situation of houses located inside the flooded areas but the water is not flow into the houses. The added grade is called grade 0. As data in the table 6.2 and chart in the figure 6.2, there is reduce gradually the flooded house area at high grades of flooding depth at two tide levels. However, there are differences of weight for each of the grades each of tide levels.

Tab. 6.2: Affected inhabitants of flooding depth grades at the tide levels in Ho Chi Minh City

No	Depth	Code	Affected Inhabitant			
			TL1.5m		TL 1.85m	
			People	%	People	%
1	Only affected	D0	852,458	87.9	1,346,083	57.3
2	0 -0.5m	D1	114,152	11.8	916,091	39.0
3	0.5 - 1.2m	D2	3,304	0.3	88,333	3.8
4	1.2 -1.8m	D3	0	0.0	719	0.0
Total			969,914	100.0	2,351,226	100.0

At the tide level 1.50m, almost flooded house area is grade 0 with 87.9% and grade 1 with 11.7% and the rest of that is grade 2. This is natural phenomenon because inhabitants can only live in the houses which are flooded the low flooding depth grade or only affected grade otherwise they can not do anything for their life. This shows that the residents living there are not really impacted so much dangerous to physical body but they can be effected to mental and a little properties. A notice in the result is there are a small number of affected inhabitants with grade 2 in the rural and new urban as shown in the table 6.3 and figure 6.3. This may be errors of the interpolation method of house foundations when the houses are located in the special zones such as location near rivers and the houses have special characteristics but the research can not get information enough so that the number of the affected inhabitants is made residuals.

However, at the tide level 1.85m there are quickly changes. Number of affected inhabitants at all the grades of flooding depth is increased with different amount so that there is a change of percentage for the flooding depth grades compared with tide level 1.50m. The number of the affected inhabitants at the grade 0 still holds the most with 55% and then is grade 1 with 40% and the third is grade 2 with 4.7% and the least is grade 3 with 0.3%. The number of the affected inhabitants increases at the grade 1 significant. The cause of this is a lot of the affected inhabitants from grade 0 at the tide level 1.5m transfers to grade 1 at this tide level. This shows that the flooded houses of the grade 0 at tide level 1.50m have ground floor elevation not much higher than the tide level.



	Tide level 1.5m (ha)	Tide level 1.85m (ha)
Only affected	852458	1346083
0 -0.5m	114152	916091
0.5 - 1.2m	3304	88333
1.2 -1.8m	0	719

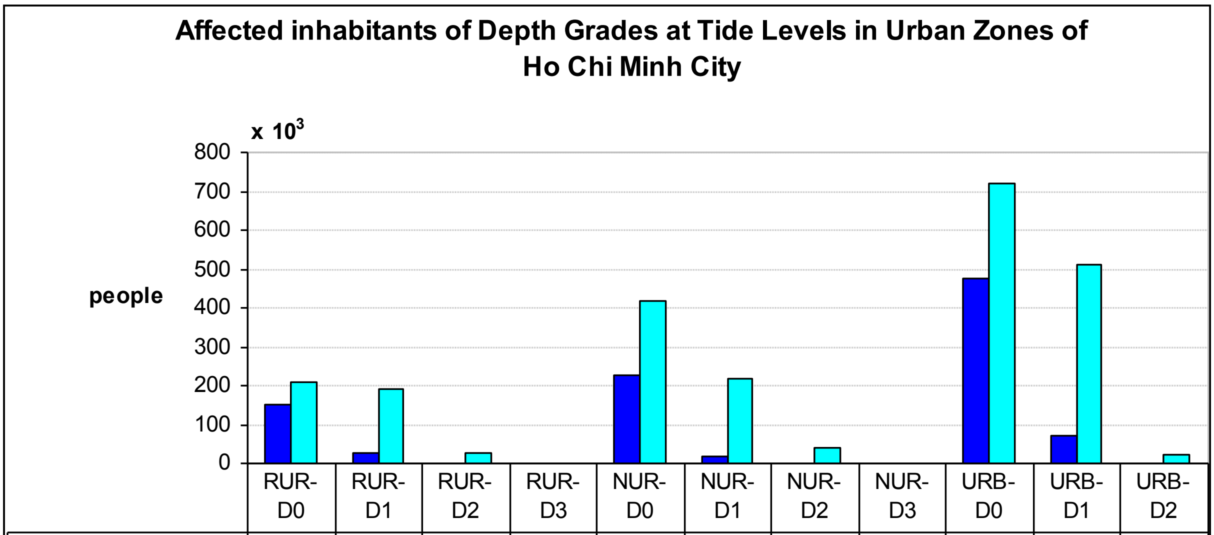
Fig. 6.2: Affected inhabitants so flooding depth grades at the tide levels in Ho Chi Minh City

Additionally, the new flooded houses are located at the low land and protected by streets whose elevation is not so much higher than 1.50m and as a result at the tide level 1.85m the number of the affected inhabitants is increased strongly at the grade 1 besides the grade 0. Therefore, the number of the affected inhabitants at the grade 0 and the grade 1 still dominates more than 95%. A warning is the number of the affected inhabitants appears at the grade 3. This shows that dangerousness to human at tide level 1.85m can be serious.

Tab. 6.3: Affected inhabitants of flooding depth grades at the tide levels in urban zones of Ho Chi Minh City

No	Urban Zones	Depth	Code	Affected Population			
				TL 1.50m		TL 1.85m	
				People	%	People	%
1	Rural	Only affected	RUR-D0	150,213	15.5	208,927	8.9
2	Rural	0 -0.5m	RUR-D1	24,986	2.6	189,376	8.1
3	Rural	0.5 - 1.2m	RUR-D2	1,992	0.2	25,691	1.1
4	Rural	1.2 -1.8m	RUR-D3	0	0.0	78	0.0
5	New Urban	Only affected	NUR-D0	226,354	23.3	416,714	17.7
6	New Urban	0 -0.5m	NUR-D1	19,941	2.1	217,550	9.3
7	New Urban	0.5 - 1.2m	NUR-D2	1,285	0.1	39,077	1.7
8	New Urban	1.2 -1.8m	NUR-D3	0	0.0	646	0.0
9	Old Center Urban	Only affected	URB-D0	475,901	49.1	720,445	30.6
10	Old Center Urban	0 -0.5m	URB-D1	69,242	7.1	509,166	21.7
11	Old Center Urban	0.5 - 1.2m	URB-D2	0	0.0	23,556	1.0
Total				969,914	100.0	2,351,226	100.0

The data in the table 6.3 and chart of figure 6.3 shows more clearly about change and distribution of flooding depth grades in the urban zones. At the tide level 1.50m in all urban zones there are the affected inhabitants at the grade 0 and grade 1 but there is a small number of the affected inhabitant at the grade 2 in the rural and new urban. The reason can be errors of the interpolation method for foundation elevation of the houses. The most attention is the number of affected inhabitants is increased in all urban zones at the tide level 1.85m.



	RUR-D0	RUR-D1	RUR-D2	RUR-D3	NUR-D0	NUR-D1	NUR-D2	NUR-D3	URB-D0	URB-D1	URB-D2
Tide level 1.50m (ha)	150213	24986	1992	0	226354	19941	1285	0	475901	69242	0
Tide level 1.85m (ha)	208927	189376	25691	78	416714	217550	39077	646	720445	509166	23556

Fig. 6.3: Affected inhabitants of flooding depth grades at the tide levels in urban zones of Ho Chi Minh City

Moreover there are new grades in all urban zones. In the rural and new urban, number of the affected inhabitants at the grade 3 is appeared and that in the old center urban occurs grade 2. The number of the affected inhabitants is increased very much at the grade 1 and the number of the affected inhabitants at this grade holds also the major portion at the tide level 1.85m in all the urban zones. The cause of the phenomenon is there is much low land regions in all urban zones such as Thu Duc District, District 2, District 7, District 9 and Binh Tan District in the new urban zone, Binh Chanh Rural District in the rural zone and Binh Thanh District, District 4, District 6 and District 8 in the old center urban in which are protected by roads at tide level 1.50m.

3.3. Duration grades

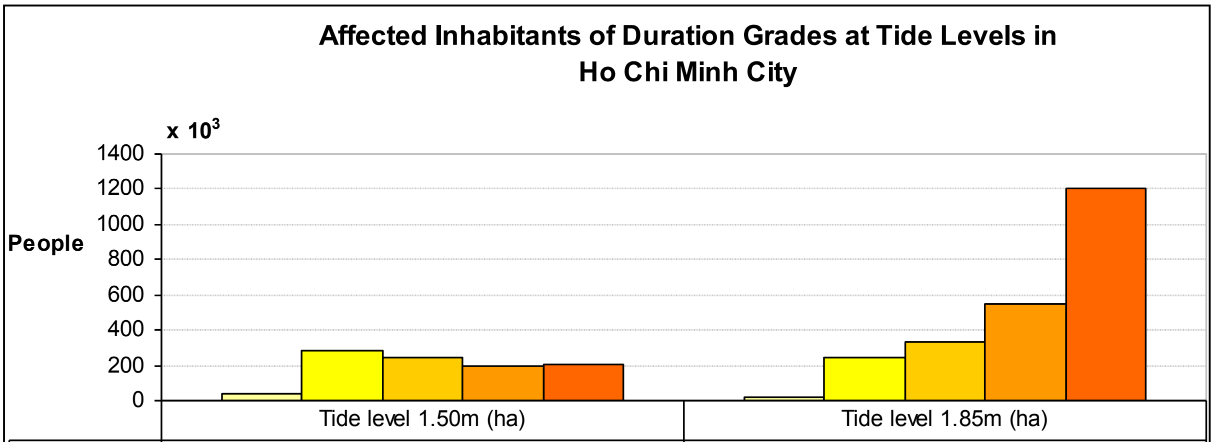
The distribution of the affected inhabitants at all the flooding duration grades is shown in table 6.4 and chart figure 6.4.

At the tide level 1.50m almost the affected inhabitants are concentrated at four the highest grades with the same percentage and at the grade 1 that holds a small percentage. This shows that the affected inhabitants of the duration are long. There are two reasons for explanation of the phenomenon. The first is tide characteristic as tide value range for the grade 1 is very short with difference between high boundary and low boundary values 1cm as shown in appendix A.1.

Tab. 6.4: Affected inhabitants of flooding duration grades at tide levels in Ho Chi Minh City

No	Duration	Code	Affected Inhabitants			
			TL 1.50m		TL 1.85m	
			People	%	People	%
1	Less 1hour	T1	39,694	4.1	17,352	0.7
2	1 - 2h	T2	284,033	29.3	241,028	10.3
3	2 - 3h	T3	246,022	25.4	337,257	14.3
4	3 - 4h	T4	196,259	20.2	550,648	23.4
5	More 4h	T5	203,906	21.0	1,204,941	51.2
Total			969,914	100.0	2,351,226	100.0

As a result, probability of the land is flooded at the grade 1 is very small. The second is only the high regions are flooded to be classified to the grade 1. But there is not much high land in Ho Chi Minh City therefore the inhabitants living in the flooded house area at the grade 1 is not much. At the tide level 1.85m, increasing the affected inhabitants are extended much more at the grades. Besides two reasons that are described above there is one more reason for this tide level. As shown in the appendix A.1, the affected inhabitants at all grades at tide level 1.50m are moved to the grade 5 at tide level 1.85m so that the number of the affected inhabitants at the grade 5 holds on more than the others. Moreover, the new flooded areas at tide level 1.85m are low land regions and protected by road when tide level 1.50m but the road elevations are not so much more than tide level 1.50m so that a lot of the flooded areas is inundated at the grade 5 and the houses located in these areas are the same situation of flooding duration. And as a result, the number of the affected inhabitants at the grade 5 holds on 51%. This shows that the dangerousness needs to be warned when tide level rises in the future.



	Tide level 1.50m (ha)	Tide level 1.85m (ha)
Less 1hour	39694	17352
1 - 2h	284033	241028
2 - 3h	246022	337257
3 - 4h	196259	550648
More 4h	203906	1204941

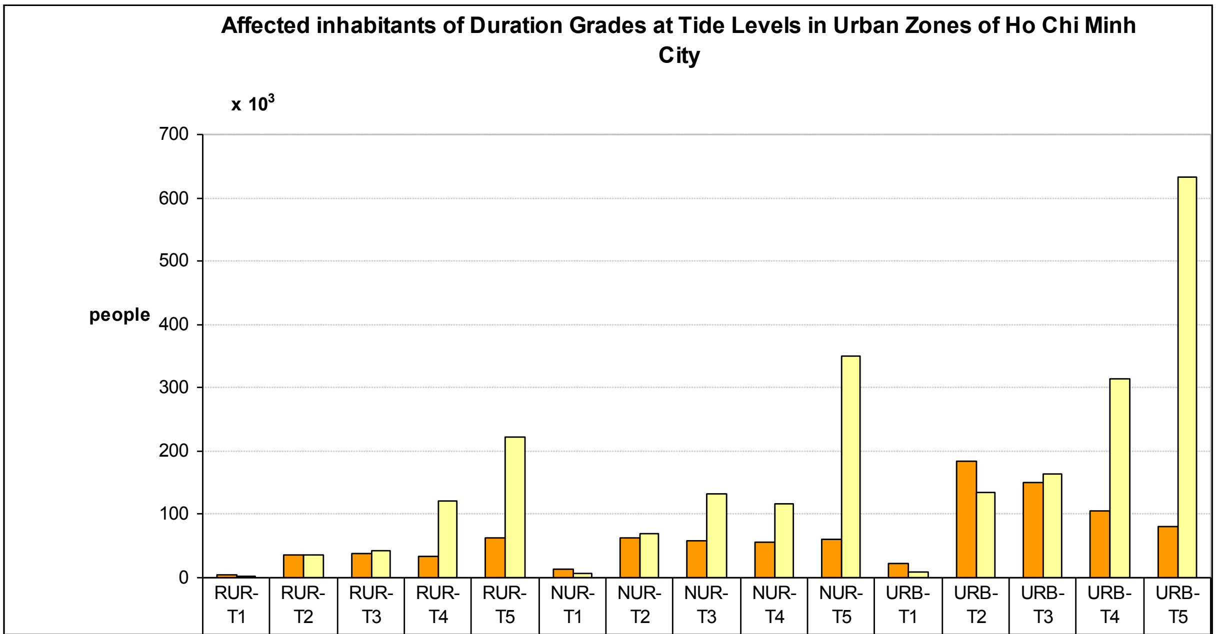
Fig. 6.4: Affected inhabitants of flooding duration grades at the tide levels in Ho Chi Minh City

To analyze insight about the distribution of the flooded house area in the urban zones, the information in table 6.5 and chart figure 6.5 shows for that. In the rural, the affected inhabitants concentrate a major portion at the grade 5 and the least at the grade 1 at two tide levels. The reason is the rural is low land regions so that almost inhabitants living in these houses in the regions are flooded long duration. In the rural at the tide level 1.85m there is increasing the affected inhabitants strongly at the grade 5 because the new flooded areas in Binh Chanh Rural District are low land regions but they are protected by road as tide level 1.50m however the road elevations are not much higher than tide level 1.50m and as a result when tide level rises the flooded areas are at grade 5 of flooding duration. That leads the number of the affected inhabitants is increased the grade 5 at tide level 1.85m.

Tab. 6.5: Affected inhabitants of flooding duration grades at the tide levels in urban zones of Ho Chi Minh City

No	Urban Zones	Duration	Code	Affected Inhabitants			
				TL 1.50m		TL 1.85m	
				People	%	People	%
1	Rural	Less 1h	RUR-T1	4,210	0.4	1,725	0.1
2	Rural	1 - 2h	RUR-T2	36,842	3.8	36,746	1.6
3	Rural	2 - 3h	RUR-T3	37,646	3.9	41,972	1.8
4	Rural	3 - 4h	RUR-T4	34,618	3.6	120,511	5.1
5	Rural	More 4h	RUR-T5	63,854	6.6	223,089	9.5
6	New Urban	Less 1h	NUR-T1	12,443	1.3	7,690	0.3
7	New Urban	1 - 2h	NUR-T2	62,118	6.4	68,865	2.9
8	New Urban	2 - 3h	NUR-T3	57,240	5.9	131,632	5.6
9	New Urban	3 - 4h	NUR-T4	55,737	5.7	116,746	5.0
10	New Urban	More 4h	NUR-T5	59,999	6.2	349,044	14.8
11	Old Center Urban	Less 1h	URB-T1	23,042	2.4	7,936	0.3
12	Old Center Urban	1 - 2h	URB-T2	185,074	19.1	135,416	5.8
13	Old Center Urban	2 - 3h	URB-T3	151,135	15.6	163,653	7.0
14	Old Center Urban	3 - 4h	URB-T4	105,903	10.9	313,391	13.3
15	Old Center Urban	More 4h	URB-T5	80,053	8.3	632,810	26.9
Total				969,914	100.0	2,351,226	100.0

In the new urban, the situation is similar to the rural however there is difference of percentages for the grades. At the tide level 1.50m the number of the affected inhabitants at the grade 1 is the least and the other grades are almost similar with the same percentage. This shows that affected inhabitant distribution of flooded houses in the regions in which slope is gradually changed. Moreover number of houses located in very low land regions is not as much as that is the rural regions. At the tide level 1.85m there is strongly increasing the number of the affected inhabitants at the grade 5. This shows that the roads help very much to protect the houses in the low land regions at tide level 1.50m but they can not do at tide level 1.85m. And additionally, this also shows that the road elevations are not much higher than tide level 1.50m and as a result the number of the affected inhabitants living in the houses protected by the roads is very vulnerable when tide level rises.



	RUR-T1	RUR-T2	RUR-T3	RUR-T4	RUR-T5	NUR-T1	NUR-T2	NUR-T3	NUR-T4	NUR-T5	URB-T1	URB-T2	URB-T3	URB-T4	URB-T5
Tide level 1.50m (ha)	4210	36842	37646	34618	63854	12443	62118	57240	55737	59999	23042	185074	151135	105903	80053
Tide level 1.85m (ha)	1725	36746	41972	120511	223089	7690	68865	131632	116746	349044	7936	135416	163653	313391	632810

Fig. 6.5: Affected inhabitants of flooding duration grades at the tide levels in urban zones of Ho Chi Minh City

In the old center urban, at the tide level 1.50m the affected inhabitants concentrate a major portion at the grade 2 and grade 3 and that reduces at the grade 4 and grade 5. The cause of the phenomenon relates to the flooded houses. In sections of flooded house assessment, the high land regions in the old center urban occupy almost and the low land regions are protected by roads. However, when tide level rises to 1.85m vulnerability to these houses is exposed with increasing of flooded house area at grade 4 and grade 5 is extremely high. The number of the affected inhabitants at the grade 1, grade 2 and grade 3 is reduced. The reason may be movement of the inhabitants living in the flooded house area of these grades at tide level 1.50m to the grade 4 and grade 5 at the tide level 1.85m. Additionally, increasing of new flooded houses in the high land regions is not as much as in the low land regions of Binh Thanh District, District 4, District 6 and District 8. These regions at tide level 1.50m are controlled by the roads to protect them for preventing inundation. Consequently, the number of the affected inhabitants living in the regions is impacted similarly to the flooded houses.

3.4. Frequency grades

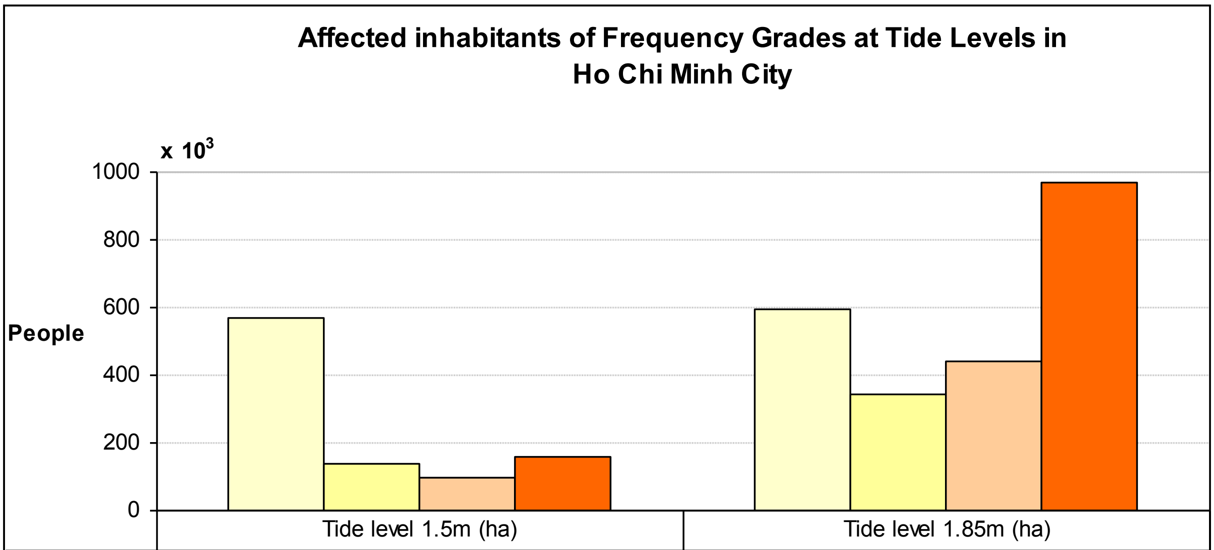
From data in table 6.6 and chart in figure 6.6, some conclusions are found. At the tide level 1.50m the flooded house area is the most with 58% at the grade 1 and that is the least with 10% at grade 3, with 15% at the grade 2 and with 17% at the grade 4. This is because population density reduces gradually from high land to low land in Ho Chi Minh City. Moreover, because tide level value ranges matching with the flooding frequency grades are not the same as each of others as shown in appendix A.2. In the appendix, the tide value range matching with flooding frequency grade 1 is large that of grade 2 and grade 3 so that the affected inhabitants at the grade 2 and grade 3 are very little. But why is the number of the affected inhabitants at the grade 4 also little? The cause of the phenomenon is the inhabitants do not like to build houses in the very low land regions and the low land regions where can build houses are protected by roads to prevent inundation. This reason is shown clearly when tide level rises to 1.85m.

Tab. 6.6: Affected inhabitants of flooding frequency grades at tide levels in Ho Chi Minh City

No	Frequency	Code	Affected Inhabitants			
			TL 1.5m		TL 1.85m	
			People	%	People	%
1	Less 1 t/m	F1	569,712	58.7	595,630	25.3
2	1 - 3 t/m	F2	140,738	14.5	342,629	14.6
3	3 - 7 t/m	F3	98,868	10.2	443,118	18.8
4	More 7 t/m	F4	160,596	16.6	969,849	41.2
Total			969,914	100.0	2,351,226	100.0

At the high tide level, although the number of the affected inhabitants at all flooding frequency grades is increased if that is compared with tide level 1.50m, increase the number of the affected inhabitants at the grade 2 is 2.4 times, at the grade 3 is 4.5 times and the most at grade 4 is 6 times as many as that of at tide level 1.50m. This shows that there are a lot of inhabitants living in the houses in the new flooded areas and the elevations of the areas are much lower than tide level 1.85m and they are inundated because the protecting roads can not help to prevent flood at high tide level. As a result at the tide level 1.85m the houses are covered by water with longer time, much deeper and more frequent appearance and the inhabitants living in the houses are faced the same as their houses.

To see more clearly impacts of flooding frequency grades to the houses in the urban zones, the data in table 6.7 and chart in figure 6.7 is very meaningful.



	Tide level 1.5m (ha)	Tide level 1.85m (ha)
Less 1 t/m	569712	595630
1 - 3 t/m	140738	342629
3 - 7 t/m	98868	443118
More 7 t/m	160596	969849

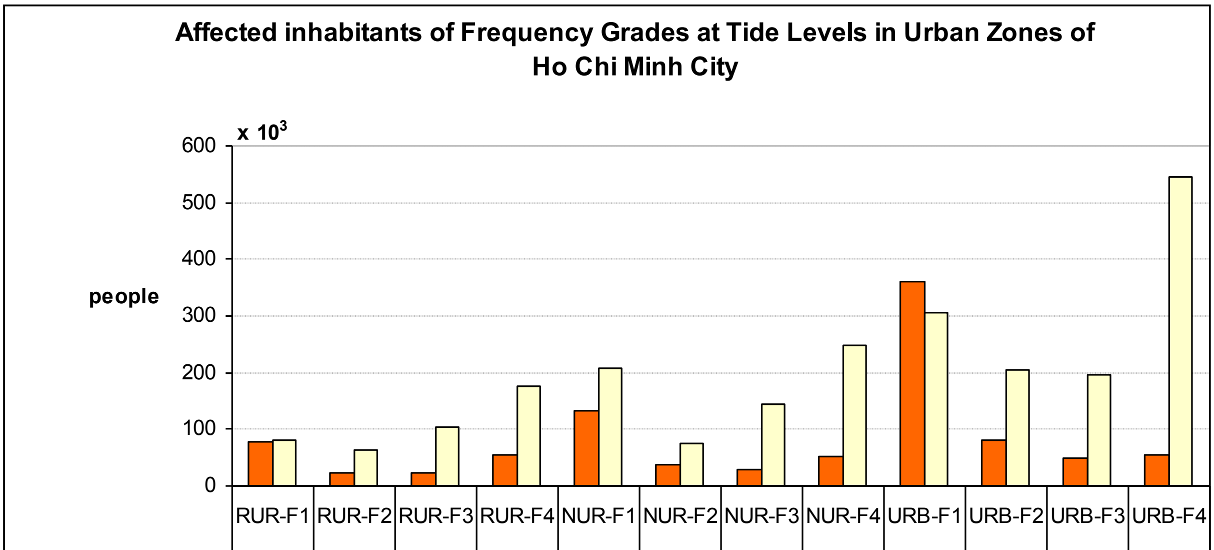
Fig. 6.6: Affected inhabitants of flooding frequency grades at the tide levels in Ho Chi Minh City

In the rural, at the tide level 1.50m almost the affected inhabitants concentrate at the grade 1 and grade 4. The number of the affected inhabitants concentrates much at the grade 1 is because the tide value range matching with flooding frequency grade 1 is large that of grade 2 and grade 3 so that probability of flooded regions classified in the grade 1 is more the others. Consequently, the number of the affected inhabitants is the same situation with their houses. The number of the affected inhabitants concentrate at the grade 4 is because in the rural almost area is low land so that there are a lot regions where are inundated very easily. At the tide level 1.85m there is strong increase of the number of the affected inhabitants at the grade 2 with 2.8 times, grade 3 with 4.8 times and grade 4 with 3.3 times as much as that does at tide level 1.50m. The reason is the new flooded area in Binh Chanh Rural District is low land regions and they are protected by roads but the road elevations are not much higher than tide level 1.50m so that when tide level rises these regions are inundated at the grade 2, grade 3 and grade 4.

Tab. 6.7: Affected inhabitants of flooding frequency grades at the tide levels in urban zones of Ho Chi Minh City

No	Urban Zones	Frequency	Code	Affected Inhabitants			
				TL 1.50m		TL 1.85m	
				People	%	People	%
1	Rural	Less 1 t/m	RUR-F1	78,695	8.1	80,434	3.4
2	Rural	1 - 3 t/m	RUR-F2	22,564	2.3	62,275	2.6
3	Rural	3 - 7 t/m	RUR-F3	21,790	2.2	104,204	4.4
4	Rural	More 7 t/m	RUR-F4	54,132	5.6	177,156	7.5
5	New Urban	Less 1 t/m	NUR-F1	131,793	13.6	208,179	8.9
6	New Urban	1 - 3 t/m	NUR-F2	36,818	3.8	74,143	3.2
7	New Urban	3 - 7 t/m	NUR-F3	28,420	2.9	144,124	6.1
8	New Urban	More 7 t/m	NUR-F4	50,529	5.2	247,544	10.5
9	Old Center Urban	Less 1 t/m	URB-F1	359,222	37.0	307,017	13.1
10	Old Center Urban	1 - 3 t/m	URB-F2	81,355	8.4	206,214	8.8
11	Old Center Urban	3 - 7 t/m	URB-F3	48,659	5.0	194,788	8.3
12	Old Center Urban	More 7 t/m	URB-F4	55,937	5.8	545,148	23.2
Total				969,914	100.0	2,351,226	100.0

In the new urban there are some differences of percentage of the flooded area at the grades compared with the rural. At the tide level 1.50m the affected inhabitants at the grade 1 is remarkable with more than 53% and the other grades are almost similar with the same percentage. Besides the reason of classification for flooding frequency characteristic with the tide value range matching with flooding frequency grade 1 is large that of grade 2 and grade 3 (see appendix A.2) the other cause is inhabitant distribution of flooded houses in the regions in which slope is gradually changed. Moreover number of the affected inhabitants living in the houses located in very low land regions is not as much as that is the rural regions. At the tide level 1.85m there is strongly increasing the number of the affected inhabitants at all grades. However, the most of the number of the affected inhabitants is extended at the grade 3 with 5.1 times and grade 4 with 4.9 times as much as that does at the tide level 1.50m. This shows that the roads help very much to protect the inhabitants living in the houses in the low land regions at tide level 1.50m but they can not do at tide level 1.85m. And additionally, this also shows that the road elevations are not much higher than tide level 1.50m and as a result the houses protected by the roads are very vulnerable when tide level rises. Consequently, the inhabitants will be impacted more serious like their houses.



	RUR-F1	RUR-F2	RUR-F3	RUR-F4	NUR-F1	NUR-F2	NUR-F3	NUR-F4	URB-F1	URB-F2	URB-F3	URB-F4
Tide level 1.50m (ha)	78695	22564	21790	54132	131793	36818	28420	50529	359222	81355	48659	55937
Tide level 1.85m (ha)	80434	62275	104204	177156	208179	74143	144124	247544	307017	206214	194788	545148

Fig. 6.7: Affected inhabitants of flooding frequency grades at the tide levels in urban zones of Ho Chi Minh City

In the old center urban, at the tide level 1.50m the number of the affected inhabitants concentrates a major portion at the grade 1 and that reduces gradually at grade 2, the grade 3 and grade 4. Besides the reason of classification for flooding frequency characteristic with the tide value range matching with flooding frequency grade 1 is large that of grade 2 and grade 3, the cause of the phenomenon is because high land regions in the old center urban occupy almost and the low land regions are protected by roads. However, when tide level rises to 1.85m vulnerability to the inhabitants living in these houses is exposed. An exception with the number of the affected inhabitants at the grade 1 is reduced the rest of the other grades is increased significantly. The number of the affected inhabitants is increased 2.5 times at the grade 2, 4 times at the grade 3 and the highest at the grade 4 with 9.7 times. Extreme increasing of the number of the affected inhabitants at grade 4 has a reason from movement the number of the affected inhabitants at the grade 2 and grade 3 at the tide level 1.50m to that at the grade 4. Additionally, increasing of new flooded houses in the high land regions is not as much as in the low land regions of Binh Thanh District, District 4, District 6 and District 8. These regions at tide level 1.50m are controlled by the roads along canals to protect them for preventing inundation. Consequently, the inhabitants living in the low land regions will be faced with the inundation similar to their houses.

Chapter 7. Flood Risk of Land Use

1. Introduction

As mention in the chapter 5, assessment of the flood risk is classed to tangible, intangible, direct and indirect damages (Proverbs & Soetanto, 2004). But with applying GIS to evaluate impacts and risks caused by flood damage, the study will focus on the direct tangible losses.

Continuously, the research conducts an assessment of the flood risk for the urban system in Ho Chi Minh City. An urban system is general definition and it presents for a lot of factors of an urban area such as: land use, transport, electric network, houses…. The flood can impact to all of the urban system. In the available researches these factors of the urban system in Ho Chi Minh City are studied (ADB, 2009a; ADB, 2009b; ADB, 2009c; WB, 2010). However, in this research with limitation of the human, time and finance resources one of the factors of the urban system in Ho Chi Minh City that is used for the assessment of flood risk is land use.

The land use is one of important system in each of regions especially in the very large urban areas like Ho Chi Minh City. The land use types are usually presented distribution and structure of the economy in the area. Therefore, the flood risk that influences inhabitant living is land use. This assessment of the flood risk will generate a forecast data that is helpful for the authority in the preparation for making adaptation plan in the development in the future of Ho Chi Minh City.

Similarly to houses and population, the assessment of flood risk to land use will also be performed on the time scenarios in 2030 with the sea level rise in the highest scenario of climate change in Ho Chi Minh City as mentioned in the section 4.4 of the chapter 3. In the scenario, the maximum tide level is 1.85m and data of this scenario will be used to assess the flood risk for houses in the study area. The assessment of flood risk is conducted at two levels 1.85m and 1.50m. The first level is the maximum and the second is the most dangerous warning level at the current in Ho Chi Minh City at Phu An tidal station. Moreover, the second level is interested as the delegation of the level at the current time.

Additionally, risk analysis is the identification of the land use types located in the areas affected by the flooding with the parameters of flood risk including: flooding duration, flooding depth and frequency of flooding. The area of the land use types that are considered to be at flooding risk is the area of the land use types exposed to flooded areas.

And the final of the assessment process of the flood risk is consideration of identifying impact grades of flooding characteristics in different regions. The assessment process is based on the flooding characteristics. Therefore, similarly to houses and population the research classifies Ho Chi Minh City to three urban zones. The first zone is called old center urban which includes the old city center and districts. The second zone is called new urban which includes the new districts that are separated from the old rural (PMVG, 1997; PMVG, 2003). And the last one is calls rural which the rest of Ho Chi Minh City is.

2. Method

In indentifying a spatial relationship of the ground objects, GIS is one of the most convenient environments for operating this task. Almost GIS systems are built sets of tool and function to support for the implementation for works that connect to the spatial relationship (DeMers, 2009; ESRI, 2004; Loi et al., 2008; Longley et al., 2005). Nowadays, these functions are applied to many disciplines relating to the spatial phenomenon such as monitoring (Gehlot & Hanssen, 2008), spatial statistic (Sarhadi, Soltani and Modarres, 2012), detecting disaster (Marfai, 2003), hazard and risk analysis (Chau, Holland, Cassells and Tuohy, 2013; Daniel, Florax and Rietveld, 2009; Nayak & Zlatanova, 2008; Sinnakaudan & Bakar, 2005; Zhaoli, Hongliang, Chengguang and Haijuan, 2012), simulation (Merwade, Cook and Coonrod, 2008; Usery et al., 2010; Vieux, 2005; Werner, 2000)… about environment and resource management (Baky, Zaman and Khan, 2012; Banzhaf, Kindler, Mueller, Metz, Reyes-Paecke and Weiland, 2013; Carrasco, Ferreira, Matias and Freire, 2012; Dewan, 2013; Qi & Altinakar, 2011; Zhou, Mikkelsen, Halsnæs and Arnbjerg-Nielsen, 2012), urban system (Campagna, 2006; Lai & Mak, 2007; Parker & Asencio, 2009; Showalter & Lu, 2010; Todini, 1999).

In this case, the research needs to identify the area of land use types which are within the flooded areas, the first thing needs to catch the flooded areas. Then based on the spatial relationship between the area of land use types and the flooded areas and applying the spatial analysis function clip on GIS (DeMers, 2009; Loi, Dinh and Nhat, 2008; Longley, Goodchild and Maguire, 2005), the objects that locate inside the potential retention areas are found.

Method to apply for identification in the land use case is considering the spatial relationship of the land use layer and the flooding maps, areas of land use types were flooded and not flooded will be determined. In the case clip function with input feature class is land use data and clip layer is the flooded areas. As a result, the types of land use that are not located inside the flooded areas are eliminated. And with the objects inside of the flooded areas, analysis about their areas, distribution of types of land use is carried out.

Risk analysis is the identification of the land use types located in the areas affected by the flooding with the parameters of flood risk including: flooding duration, flooding depth and frequency of flooding. The land use types that are considered to be at flooding risk are the regions of land use types exposed to flooded areas. Therefore, similarly to the houses and population, the land use types will be evaluated grades of flood risk based on the flood characteristics including flooded area, depth, duration and frequency. The analysis and assessment of flood risk on land use types are followed classifying the grades of flood characteristics that are described in the sections 6.3.2, 6.4.2 and 6.5.2 in the chapter 4.

The land use data in the research is based on the urban structure types (UST) from the project Megacity City Research Project. Ho Chi Minh - Integrative Urban and Environmental Planning Adaptation to Climate Change Framework. And the land use classes are reclassified for suitable assessment in the research. Land use is usually classified to a lot of types based on the use purposes so that there are too many land use types in the detail. However, to assess the flood risk to the settlement areas, the research classifies land use in Ho Chi Minh City to four classes.

The first is industry land use type which is zones for manufactories and factories of the producing companies or organizations. The second is public land use type which is zones with the constructions for services including public service and government structures. The third is resident land use type which is zones for inhabitants living and the last one is open space land use type which is the rest in Ho Chi Minh City. The matching between UST and classes of land use types is shown in the appendix C.

Tab. 7.1: Land use types in the research

No	Land Use	Abbreviation
1	Industry	IND
2	Public	PUB
3	Resident	RES
4	Open Space	OSP

This classification of land use types to assess of flood risk is different to the available researches. In the available researches, the land use types are classified by consideration of land cover types that influence to the hydrological and hydraulic processes of the surface flow impacting to the flood simulation (ADB, 2009a; ADB, 2009b; ADB, 2009c; WB, 2010). Otherwise, the classification of the land use types focuses flood risk can cause losses of economic aspects for the development plan in Ho Chi Minh City in the future so that there is a change in the structure of the distribution of the economic fields caused by losses of the matching land use types with the economic fields.

3. Results and discussion

3.1. Affected areas

The result of flooded land use types is shown in the figure 7.1 and figure 7.2 at two levels 1.50m and 1.85m. Additionally, data in the table 7.2 and figure 7.3 shows flooded area of the land use types at all tide levels. At all tide levels, the open space area is flooded the most and the resident is the second, the third is industry and the least is public. This is because the total areas of these land use types hold on with the same situation. Total area of open space area is the most, the resident is the second, the next is industry and the least is public.

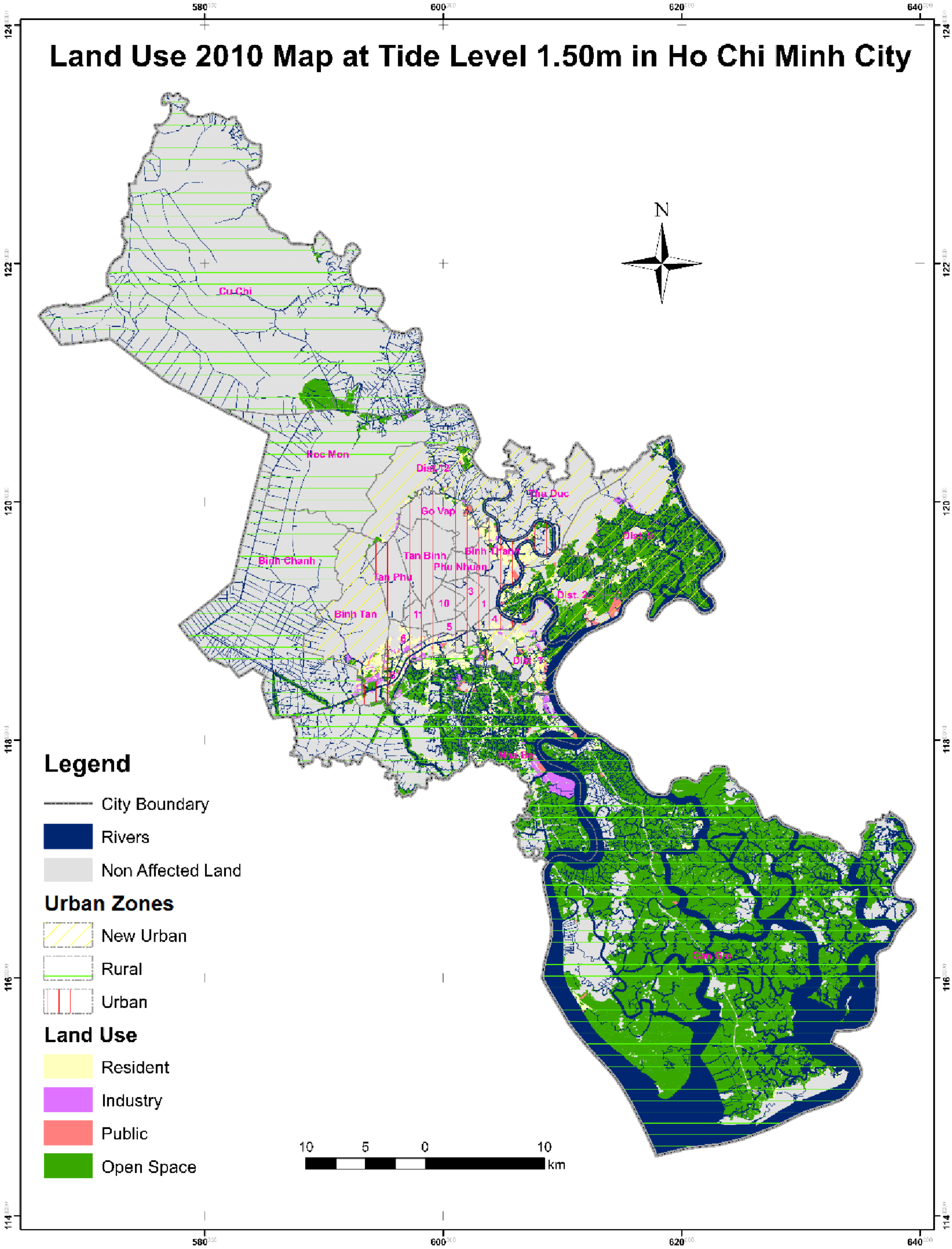


Fig. 7.1: Flooded land use maps at 1.50m tide levels in Ho Chi Minh City

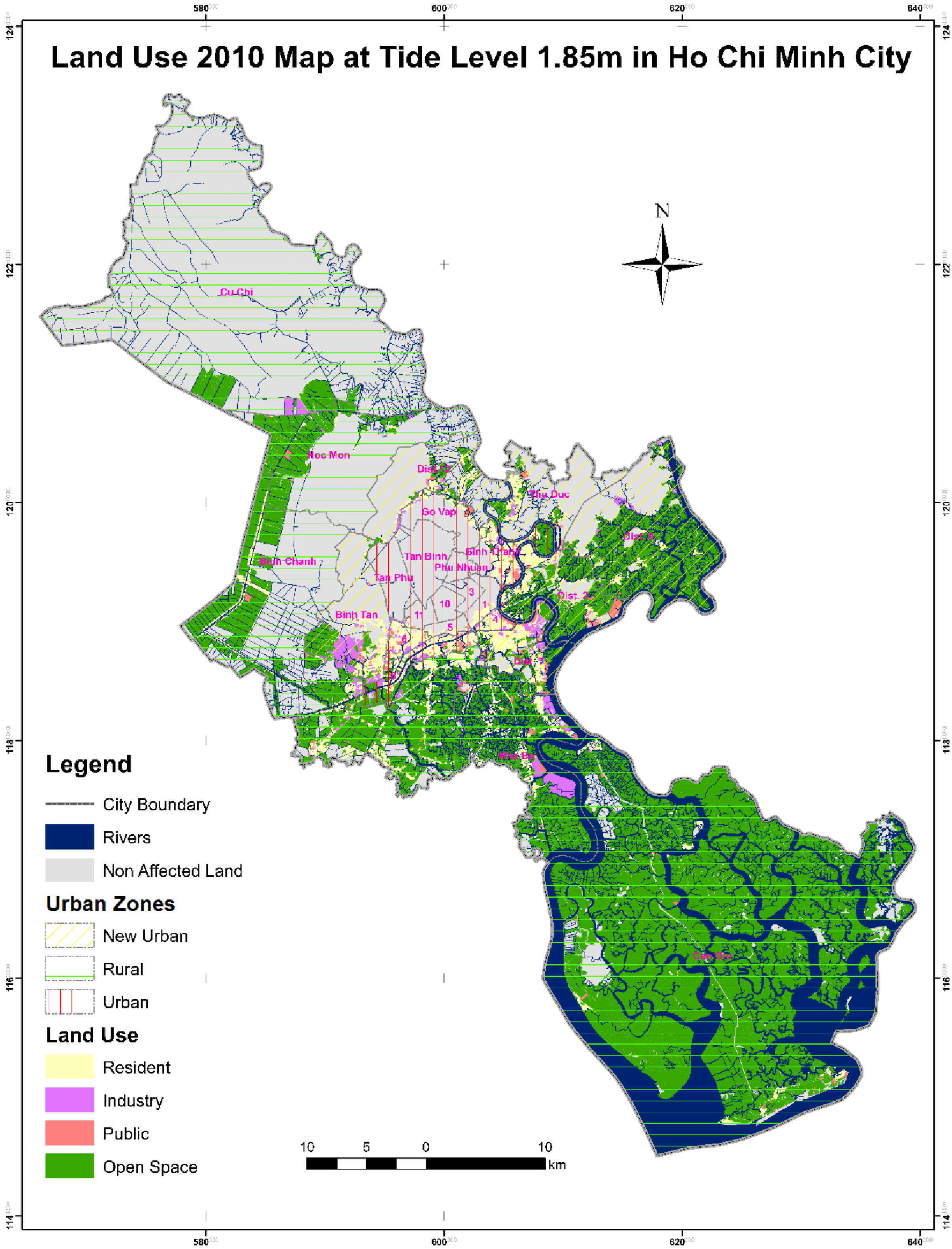


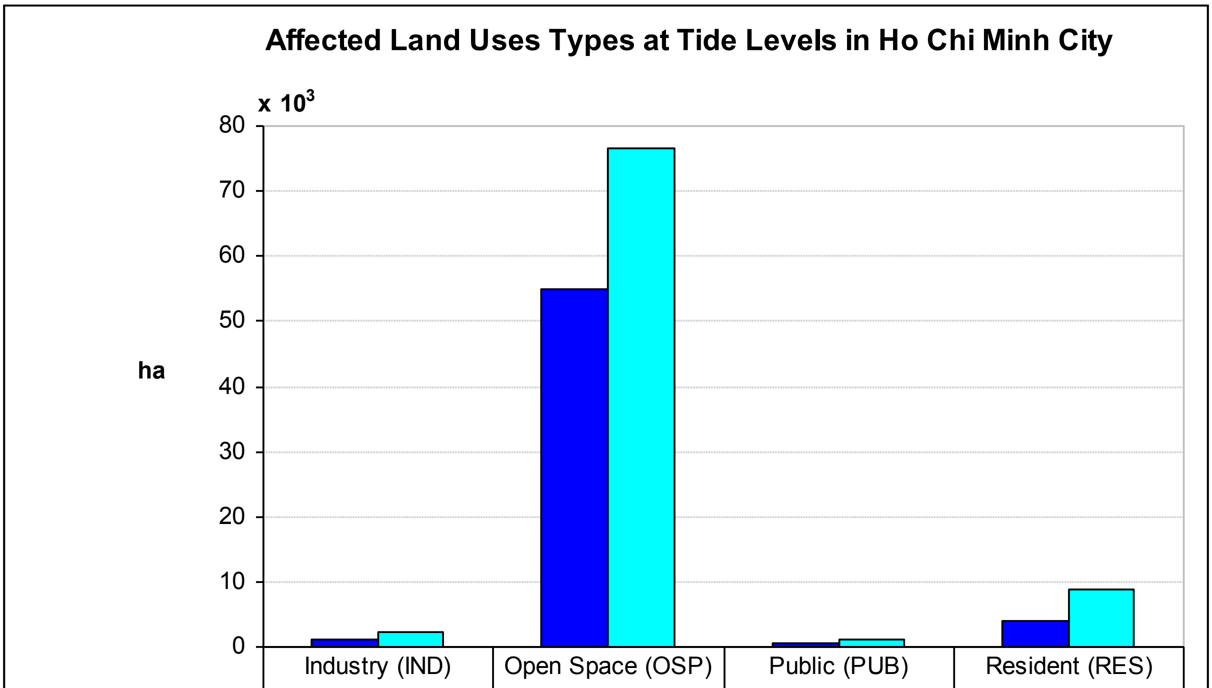
Fig. 7.2: Flooded land use maps at 1.85m tide levels in Ho Chi Minh City

Tab. 7.2: Areas of affected land use types at the tide levels in Ho Chi Minh City

No	Land Use	Flooded Area				Total Areas (ha)
		TL 1.50m		TL 1.85m		
		ha	%	ha	%	
1	Industry	1,025	1.7	2,314	2.6	5,937
2	Open Space	55,031	90.9	76,530	86.3	133,703
3	Public	545	0.9	1,093	1.2	5,250
4	Resident	3,932	6.5	8,763	9.9	27,271
Total		60,533	100.0	88,700	100.0	172,161

At the tide level 1.50m flooded area of the open space makes up 90.9% and that of public only holds on 0.9%, besides that of the resident holds on 6.5% and the industry is 1.7%. The reason is almost open space area is used to plant trees in the low land regions with mangrove forest in Can Gio Rural District and rice – crop fields in the Binh Chanh Rural District as shown in the figure 7. 1. Public land use area is the least because this type occupies a little percentage of total areas and this land use type is usually planned and constructed in the higher land regions for each of the districts. Otherwise, the industry land use type is one of the types is developed for recent times so that there is not much the rest high land regions to be chosen the same as the public land use type and therefore a lot of new industry parks have been developed in the lower land regions. Consequently, the flooded area of the industry land use type is made up more than the public. For the resident land use type, the flooded area of this type is more than the public and industry because the resident type has total area more than the others exceptionally the open space type. Moreover, for the recent decades urbanization is very quick and there is not much high land area to develop inhabitants so that the inhabitants have to construct to the lower land regions. These help for the flooded area of the resident type is increased.

At the tide level 1.85m, all land use types increase flooded area more than that do at tide level 1.50m. Therein, the most speed up of increasing flooded area is build up land use types with nearly 2 times as many as that do at tide level 1.50m. However, absolute value changes the most flooded area which is still the open space land use type. At this tide level, the percentage of open space land use type area still holds the most with 86.3% and the others are held on 2.6% for the industry type, 1.2% for the public type and 9.9% for the resident type. The reason to explain for speed up flooded area of the land use types is almost floodable area of the open space type is inundated already at tide level 1.50m, and the other floodable areas of the open space is protected by roads in the rice – crop fields in Binh Chanh Rural District.



	Industry (IND)	Open Space (OSP)	Public (PUB)	Resident (RES)
Tide level 1.50m (ha)	1025	55031	545	3932
Tide level 1.85m (ha)	2314	76530	1093	8763

Fig. 7.3: Areas of affected land use types at the tide levels in Ho Chi Minh City

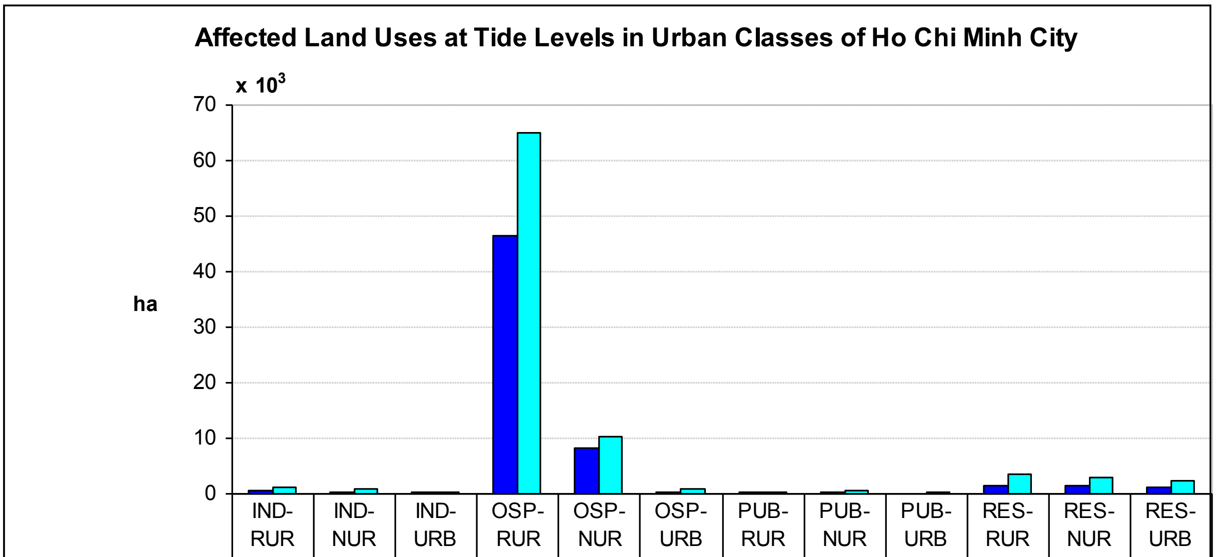
Therefore when tide level rises to 1.85m, the roads can not protect for the regions and their areas are flooded much less than the flooded area at tide level 1.50m. For the other land use types, the reason is the same when the floodable areas of these types are protected by the roads at tide level 1.50m but can not help the regions to prevent at tide level 1.85m so that the flooded area at the high tide level is increased strongly.

To analyze more insight of the flooded area of the land use types, table 7.3, figure 7.1, figure 7.2 and figure 7.4 show the data of the flooded area at the urban zones that helps to know the urbanization to the distribution of the land use types in Ho Chi Minh City. In general, the land use types have different scopes of flood impacts in the different urban zones.

Tab. 7.3: Flooded areas of land use types at the tide levels in urban zones of Ho Chi Minh City

No	Land Use	Urban Zones	Code	Flooded Areas			
				TL 1.50m		TL 1.85m	
				ha	%	ha	%
1	Industry	Rural	IND-RUR	597	1.0	1,034	1.2
2	Industry	New Urban	IND-NUR	280	0.5	965	1.1
3	Industry	Old Center Urban	IND-URB	148	0.2	316	0.4
4	Open Space	Rural	OSP-RUR	46,380	76.6	65,137	73.4
5	Open Space	New Urban	OSP-NUR	8,216	13.6	10,428	11.8
6	Open Space	Old Center Urban	OSP-URB	436	0.7	965	1.1
7	Public	Rural	PUB-RUR	150	0.2	333	0.4
8	Public	New Urban	PUB-NUR	266	0.4	479	0.5
9	Public	Old Center Urban	PUB-URB	128	0.2	282	0.3
10	Resident	Rural	RES-RUR	1,419	2.3	3,402	3.8
11	Resident	New Urban	RES-NUR	1,336	2.2	2,952	3.3
12	Resident	Old Center Urban	RES-URB	1,176	1.9	2,409	2.7
Total				60,533	100.0	88,700	100.0

For the industry land use type, at the tide level 1.50m, the flooded area is distributed the most in the rural regions, less than in the new urban and the least in the old center urban. The reason is this land use type is moved to further regions from old center of the city. The further regions are located in the rural such as Nha Be Rural District and new urban regions such as Binh Tan District, District 2, and District 9. Consequently, there is an arrangement of the industry parks in the city. The distribution of the industry parks bases on their areas. The industry parks with larger area are the rural regions and the smaller is the new urban and the least is the old center urban. Moreover, the terrain decreases from the old center urban to the rural so that the industry parks moved have more ability to be inundated. At the tide level 1.85m, the flooded area of the industry type is increased in all the urban zones. The most increasing is the new urban with 3.4 times as much as at tide level 1.50m. The cause is there are many industry parks in the Binh Tan District and District 7 are inundated so that the flooded area in the urban zone is extended. The flooded area in the old center urban is increased for the second with 2.1 times. Industry areas in the old center urban are extended because there are a lot of regions of low land in District 4, District 6, District 8 and Binh Thanh District are impacted by flood. These regions have low elevation but they are protected by roads so that at the tide level 1.50m they are not inundated. In the rural the low speed up of the flooded industry area but the absolute value is still very high. This is because at the tide level 1.50m there are a lot of the flooded area of the industry land use type in Nha Be Rural District is inundated already and when tide level rises there is a small flooded industry area in the Cu Chi Rural District is impacted.



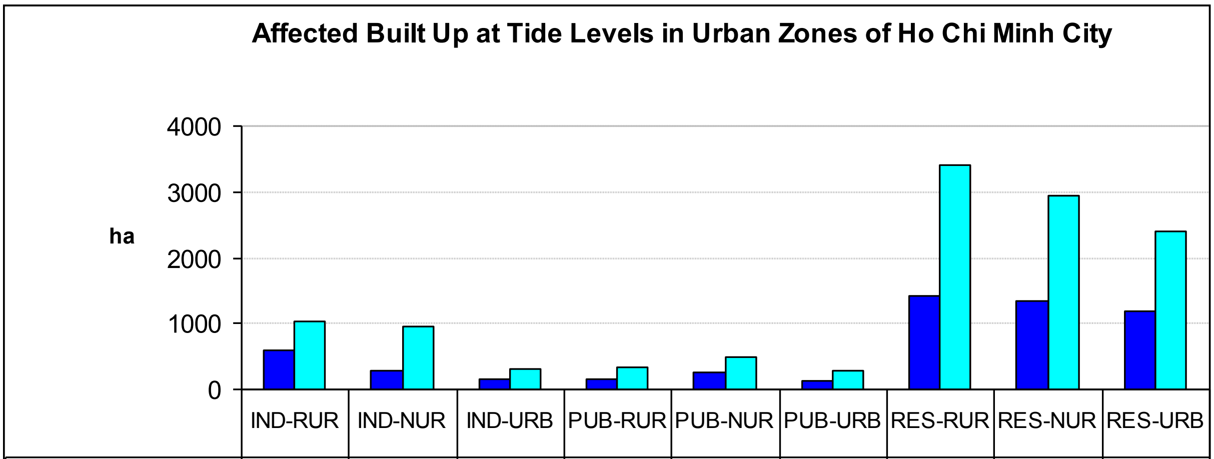
	IND-RUR	IND-NUR	IND-URB	OSP-RUR	OSP-NUR	OSP-URB	PUB-RUR	PUB-NUR	PUB-URB	RES-RUR	RES-NUR	RES-URB
Tide level 1.50m (ha)	597	280	148	46380	8216	436	150	266	128	1419	1336	1176
Tide level 1.85m (ha)	1034	965	316	65137	10428	965	333	479	282	3402	2952	2409

Fig. 7.4: Flooded areas of land use types at the tide levels in urban zones Ho Chi Minh City

For the open space land use type, there is not unusual for distribution in the urban zones. At two tide levels, the flooded area is still distributed the most in the rural regions, less than in the new urban and the least in the old center urban. This is a understandable thing because urbanization processing the old center urban regions have very little open space area and then the new urban is developed therefore area of the open space type in the new urban is more than that in the old center urban and the most area of the open space type is distributed in the rural regions. Besides, the terrain changes lowly from the old center urban to the rural so that the flooded area of the open space type increases from the old center urban to the rural.

For the public land use type, at the tide level 1.50m the most flooded area is the new urban and the less is the rural and the least is the old center urban. A question is given here. Why is there a lot of the public land use type in the old center urban but the flooded area of the public type in the new urban is the most? The reason is the old center urban has terrain is higher than the new urban and the low land regions are protected by roads. In the rural, this land use type is not much and concentrated in the town where have roads to protect low land regions so that the public type in the rural is inundated less than the new urban. In the new urban there is a problem with some area of the public type is constructed close the rivers but there is no really structures to protect such as harbors in the District 2 and District 7. At the tide level 1.85m, the flooded area of the public type is increased all the urban zones with 2 times as much as that is tide level 1.50m. The flooded area holds on the most in the new urban because all the districts in this urban zone are impacted by flood at the tide level 1.85m. In the rural there are public regions in Binh Chanh Rural District, Hoc Mon Rural District and Can Gio Rural District are flooded additionally. In the old center urban, there are low land regions in District 4, District 6, District 8 and Binh Thanh District are inundated. The new flooded areas in all the urban zones are inundated at the tide level 1.85m but they are not impacted at tide level 1.50m because they are protected by the roads but the road elevations are not high enough at tide level 1.85m so that these regions can not prevent an inundation.

For the resident land use type, at the tide level 1.50m the flooded area of all urban zones is inundated similarly. The reason is the residential regions in all the urban zones are normal protected by roads, there are only some regions where have not good infrastructures are inundated. However, at the tide level 1.85m the flooded area of the resident type is extended in all the urban zones but the most is the rural and the least is the old center urban. The cause is the rural contains very much low land and when tide level rises the roads can not support for preventing inundation so that there are a lot of large regions Binh Chanh Rural District and Nha Be Rural District are flooded. The increasing flooded area in the new urban and the old center urban is similar but why in these urban zones the new flooded area is less than the rural? Because the new flooded area in these urban zones is less than the rural. Therefore distribution of the flooded area is reduced from the rural to the old center urban as shown in the figure 7.4.



	IND-RUR	IND-NUR	IND-URB	PUB-RUR	PUB-NUR	PUB-URB	RES-RUR	RES-NUR	RES-URB
Tide level 1.50m (ha)	597	280	148	150	266	128	1419	1336	1176
Tide level 1.85m (ha)	1034	965	316	333	479	282	3402	2952	2409

Fig. 7.5: Flooded areas of built up types at the tide levels in urban zones of Ho Chi Minh City

If consideration of the flood impacts to only the build up land use types as shown in the figure 7.5 the flooded area of the resident type holds on the most and the extension of flooded area when tide level rises is the highest. The least flooded area is the public type. This is because the total area of the resident type is the most, the less is the resident is the industry type and the least is public.

As above analysis, the flooded area of the open space land use type always holds on more 90% of the total flooded area therefore when the flooded area of this type is shown with each others in the same chart so that the values of the others are not very visible and analyzed. Moreover, the build up land use types are very important for the analysis because they relate to the damage of inhabitants and their properties. Consequently, in the next sections of analysis for the flooding characteristics, charts will be displayed with the build up land use types. But in the tables the open space land use type is still kept and analyze.

3.2. Depth grades

The result of the flooded area for all land use types at the grades of the flooding depth is shown in table 7.4 and chart in the figure 7.6. In the general, at the tide level 1.50m area of all the build up land use types is flooded at the highest grade that is grade 3 and the open space land use type is flooded deeper with the highest grade is grade 4. But when the tide level rises to 1.85m, the flooded area of all the land use types reaches to grade 4. This makes more dangerous for the human and the structures.

For the industry land use type, at the tide level 1.50m the flooded area is concentrated at the grade 1 with 53%, the grade 2 with 46% and very little at the grade 3 with 1%. The cause is the industry regions are developed newly and located in the low land but terrain of the regions is not much lower than the tide level 1.50m. Therefore almost the flooded area is grade 1 and grade 2. At the tide level 1.85m, flooded area at the old grades is increased. The flooded area increases 450ha at the grade 1, the grade 2 is 526ha and the grade 3 is 312ha. The new flooded area appears is because low land regions in the Binh Chanh Rural District and District 7 at the tide level 1.50m are protected by roads, however the road elevations can not help these regions to prevent inundation at the tide level 1.85m. As a result, they are flooded and the flooded areas hold the high grade or deeper inundation (see appendix B.1).

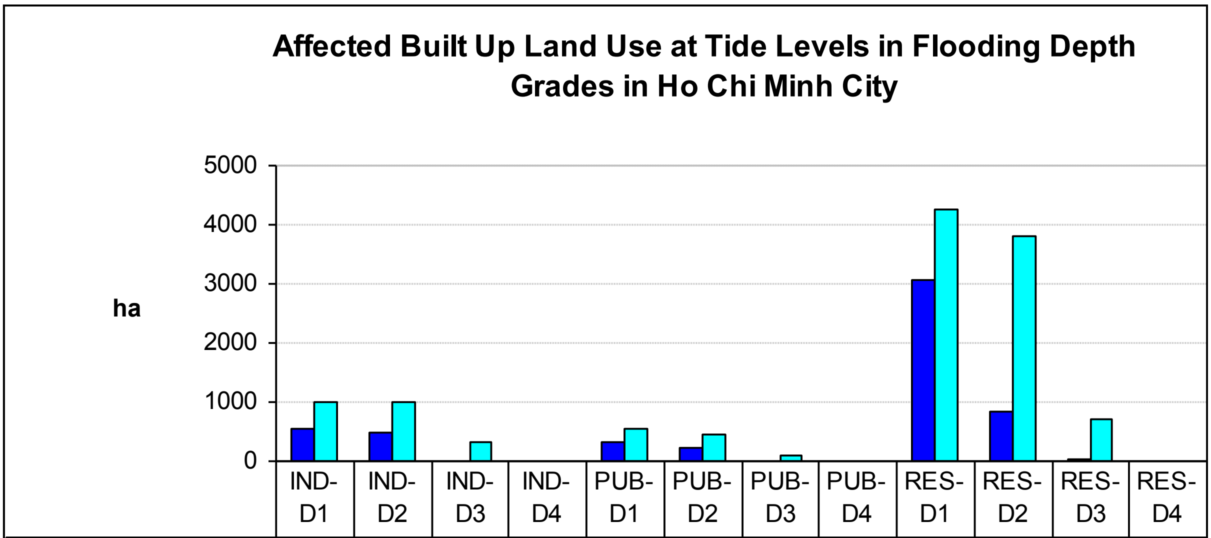
For the open space land use type, at the tide level 1.50m a situation is similar to the industry type as almost the flooded area is at the grade 1 and grade 2. However, there is a small flooded area at the grade 4 at the tide level 1.50m in the regions very close with main rivers in Can Gio Rural District. The flooded area can make a high dangerousness for human living around the regions. When the tide level rises to 1.85m, the flooded area at the grade 1 is decreased but increased extremely at the grade 2 and grade 3 besides extended at the grade 4. The reason is all low land regions are occupied by open space land use type. Therefore when the tide level raises the flooded area at the grade 1 is moved to the grade 2 or grade 3 and no high land regions are not extended for the new flooded area so that the flooded area at the grade 1 is reduced. The lowest land is increased flooding depth to grade 4.

For the public land use type, almost area is flooded at the grade 1 and grade 2 because this land use type is usually distributed in the higher land regions. This is shown clearly at the tide level 1.50m that is almost the flooded area is the grade 1 and grade 2. There is only a small flooded area belongs the grade 3 in Can Gio Rural District. Distribution of the flooded area at the tide level 1.85m is same as at tide level 1.50m. The flooded area at the grade 1 and the grade 2 holds major portions. Due to tide level rise as a result all the grades have increase about the flooded area. About absolute values, the flooded area is increased the most at the grade 2, less is grade 1, grade 3 and the least is the grade 4. At this tide level there is appearance of the grade 4 in spite of a small flooded areas. However, the appearance makes more dangerous for the human living around the regions. Development of the new flooded area in the new urban and the old center urban (see appendix B.1) show that the roads which help to protect the low land regions in these urban zones can not support for these regions preventing flooded at the tide level 1.85m. The flooded areas in the new urban and the old center urban are the grade 1 and grade 2. The flooded area at grade 3 and grade 4 concentrates in the rural and the lowest land regions of the new urban.

Tab. 7.4: Flooded areas of built up types at the tide levels in flooding depth grades in Ho Chi Minh City

No	Land Uses	Depth	Code	Flooded Areas			
				TL 1.50m		TL 1.85m	
				ha	%	ha	%
1	Industry	0 - 0.5m	IND-D1	543	0.9	993	1.1
2	Industry	0.5 - 1.2m	IND-D2	473	0.8	998	1.1
3	Industry	1.2 - 1.8m	IND-D3	10	0.0	322	0.4
4	Industry	Deeper 1.8m	IND-D4	0	0.0	0	0.0
5	Open Space	0 - 0.5m	OSP-D1	25,604	42.3	14,268	16.1
6	Open Space	0.5 - 1.2m	OSP-D2	28,475	47.0	47,068	53.1
7	Open Space	1.2 - 1.8m	OSP-D3	926	1.5	15,052	17.0
8	Open Space	Deeper 1.8m	OSP-D4	26	0.0	142	0.2
9	Public	0 - 0.5m	PUB-D1	319	0.5	533	0.6
10	Public	0.5 - 1.2m	PUB-D2	213	0.4	454	0.5
11	Public	1.2 - 1.8m	PUB-D3	12	0.0	105	0.1
12	Public	Deeper 1.8m	PUB-D4	0	0.0	2	0.0
13	Resident	0 - 0.5m	RES-D1	3,064	5.1	4,254	4.8
14	Resident	0.5 - 1.2m	RES-D2	844	1.4	3,801	4.3
15	Resident	1.2 - 1.8m	RES-D3	24	0.0	705	0.8
16	Resident	Deeper 1.8m	RES-D4	0	0.0	4	0.0
Total				60,533	100.0	88,700	100.0

For the resident land use type, the flooded area concentrates the major portion at the low grades and less at the higher grades of the flooding depth. This shows the urbanization is inhabitants move and live in the high land regions firstly and then in the lower land regions and further city center. Besides the resident regions in the low land are protected by the roads so that they can not be flooded deep. At the tide level 1.50m, there is 78% the flooded area at the grade 1 and 21% the flooded area at the grade 2 and a small rest of the flooded area at the grade 3. Distribution of the flooded area at the grade 1 in the all urban zones is similar. At the grade 2 the flooded area in the rural is major because in the rural there are low lands are developed to resident but they have no high roads for protecting inundation (see appendix B.1).



	IND-D1	IND-D2	IND-D3	IND-D4	PUB-D1	PUB-D2	PUB-D3	PUB-D4	RES-D1	RES-D2	RES-D3	RES-D4
Tide level 1.50m (ha)	542.6	472.7	10.0	0.0	318.8	213.4	12.4	0.0	3063.8	843.7	24.0	0.0
Tidel level 1.85m (ha)	992.7	998.4	322.1	0.5	532.6	453.9	104.7	2.1	4253.7	3801.1	704.7	3.8

Fig. 7.6: Flooded areas of built up types at the tide levels in flooding depth grades in Ho Chi Minh City

When the tide level raises to 1.85m all the grades of flooding depth are increased flooded area. The flooded area holds on the most is the grade 1 but increasing flooded area is the grade 2. This gives information that is the roads can not protect for the low lands when tide level reaches to 1.85m. Extension of the flooded area occurs at the grade 1 the most popularly in the District 4, District 6, District 8 and Binh Thanh District in the old center urban. The old center urban contributes almost the flooded area at the grade 1 because this urban zone is capturing the higher land than the others so that the flooded area is less serious. At the grade 2, the flooded area in the rural is increased the most and less is the new urban because movement of the flooded area from grade 1 at the tide level 1.50m to grade 2 when tide level rises. At the grade 3, the flooded area is increased almost in the rural and the new urban and in the old center urban is very little because the old center urban is usually the higher land. There is a small flooded area at the grade 4. This makes a warning to the inhabitants living there for precautions of the dangerousness.

3.3. Duration grades

The result of the flooded area for all land use types at the grades of the flooding duration is shown in table 7.5 and chart in the figure 7.7. In the general, all the land use types are flooded at all the flooding duration grades at two tide levels. Additionally, the information in the table shows a trend of the flooded area that is increasing gradually flooded area from the low grade to high grade. That means the higher grade is the more flooded area does. This show there is a lot of the regions are impacted by flood for a long duration. The reason is tide characteristic as tide value range for the grade 1 is very short with difference between high boundary and low boundary values 1cm (see appendix A.1). And otherwise, the tide value range for the grade 5 is very large. As a result, probability of the land is flooded at the grade 1 is lower and at the grade 5 is higher. The other reason is almost the regions in Ho Chi Minh City are low land and area of the low land increases gradually matching with decreasing terrain elevation. Consequently, the higher grade is the more flooded area does. Another general conclusion is flooded area of each of the land use types is increased when tide level rises from 1.50m to 1.85m.

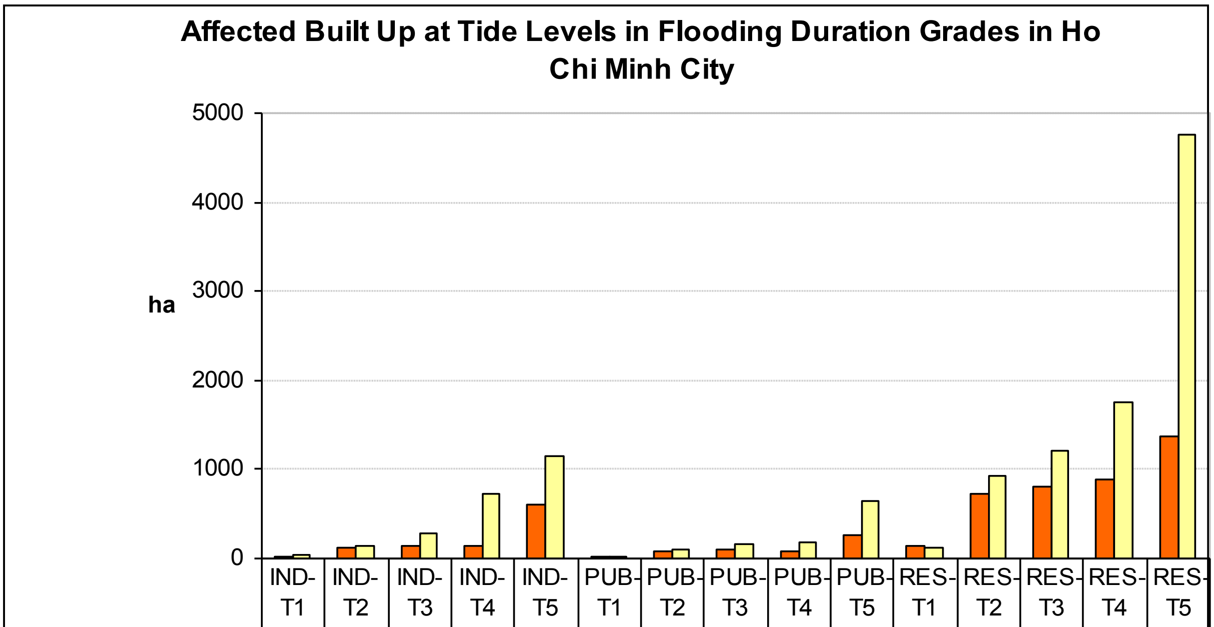
For the industry land use type, at the tide level 1.50m the flooded area is concentrated at the grade 5 with 58% and the least is the grade 3 with 1%. The flooded area of the other grades is similar with 13%. The first reason is tide characteristic that is tide value range for the grade 1 is very short with difference between high boundary and low boundary values 1cm (see appendix A.1). And otherwise, the tide value range for the grade 5 is very large. The second reason is the industry regions are developed newly and located in the low land of the rural and new urban regions and terrain of the regions is lower than 1.30m. Therefore there is difference of flooded area between grade 1 and grade 5. At the tide level 1.85m, flooded area at all grades is increased. The increasing flooded area at the grade 4 is the most and the least is grade 5. The reason is the new flooded area in low land regions in the Binh Chanh Rural District and District 7 at the tide level 1.50m are protected by roads, however the road elevations can not help these regions to prevent inundation at the tide level 1.85m. As a result, they are flooded and the flooded areas hold the high grade or deeper inundation (see appendix B.2, figure 7.1 and figure 7.2).

Tab. 7.5: Flooded areas of built up types at the tide levels in flooding duration grades in Ho Chi Minh City

No	Land Uses	Duration	Code	Flooded Areas			
				TL 1.50m		TL 1.85m	
				ha	%	ha	%
1	Industry	Less 1 hour	IND-T1	13	0.0	34	0.0
2	Industry	1 - 2 hours	IND-T2	120	0.2	150	0.2
3	Industry	2 - 3 hours	IND-T3	145	0.2	272	0.3
4	Industry	3 - 4 hours	IND-T4	151	0.2	716	0.8
5	Industry	More 4 hours	IND-T5	597	1.0	1,141	1.3
6	Open Space	Less 1 hour	OSP-T1	406	0.7	171	0.2
7	Open Space	1 - 2 hours	OSP-T2	2,561	4.2	4,834	5.4
8	Open Space	2 - 3 hours	OSP-T3	4,458	7.4	4,204	4.7
9	Open Space	3 - 4 hours	OSP-T4	7,627	12.6	7,927	8.9
10	Open Space	More 4 hours	OSP-T5	39,980	66.0	59,394	67.0
11	Public	Less 1 hour	PUB-T1	15	0.0	26	0.0
12	Public	1 - 2 hours	PUB-T2	78	0.1	93	0.1
13	Public	2 - 3 hours	PUB-T3	93	0.2	155	0.2
14	Public	3 - 4 hours	PUB-T4	87	0.1	181	0.2
15	Public	More 4 hours	PUB-T5	271	0.4	639	0.7
16	Resident	Less 1 hour	RES-T1	134	0.2	112	0.1
17	Resident	1 - 2 hours	RES-T2	734	1.2	932	1.1
18	Resident	2 - 3 hours	RES-T3	814	1.3	1,202	1.4
19	Resident	3 - 4 hours	RES-T4	880	1.5	1,761	2.0
20	Resident	More 4 hours	RES-T5	1,369	2.3	4,756	5.4
Total				60,533	100.0	88,700	100.0

In a general trend, for the open space land use type, the flooded area still concentrates the most in the highest grade of the flooding duration. At the tide level 1.50m almost the flooded area is at the grade 4 with 14% and grade 5 with 73%. The other grades hold on less than the flooded area at the grade 4 and grade 5. The least is grade 1 with 1%. The reason is open space land use type is distributed in the lowest regions of Ho Chi Minh City. When the tide level rises to 1.85m, the flooded area at the grade 5 is still increased and reached to 78%. The other grades are changed with the different amount. The flooded area at the grade 1 is decreased because there is not much high land to be inundated. As shown in the appendix A.1, the flooded area at all grades at tide level 1.50m are moved to the grade 5 at tide level 1.85m so that the number of the flooded area at the grade 5 holds on more than the others. Besides the new flooded areas are low lands in rice – crop fields of Binh Chanh Rural District and the areas are protected by roads as tide level 1.50m but the road elevations are not much higher than 1.50m so that at tide level 1.85m the areas are inundated at the high grades of the flooding duration (see appendix B.2, figure 7.1 and figure 7.2).

For the public land use type, there is always a priority of this land use type when planners make land use planning. This type is disposed in the higher lands of districts. As a result, the flooded area is less than the other land use types. For the flooding duration, the flooded area at the different grades has more variations than the other land use types. This show at the tide level 1.50m, the flooded area at the grade 5 still makes up 50% but the flooded area at the lower grades holds on a large percentage. The reasons are similar with the other land use types. The urban zone where the flooded area occupies the most is the new urban in District 2 because there are some new harbors constructed and developed here. And in these regions almost area is low terrain so that the flooded area is inundated long duration. The distribution of the flooded area at the tide level 1.85m is the same as tide level 1.50m. The most flooded area is grade 5 and the least is grade 1. When the tide level raises to 1.85m all the grades of flooding duration are increased flooded area. The absolute values of change the flooded area is increased the most at the grade 5 and then the flooded area is reduced gradually matching with the lower grades. In the all urban zones the flooded area of the public type is extended. In the rural the flooded area is extended in Binh Chanh Rural District, Can Gio Rural District, Nha Be Rural District and Hoc Mon Rural District. In the new urban the flooded area is increased in Thu Duc District, Binh Tan District, District 7 and District 12. In the other urban zone, the flooded area is added in District 4, District 6, and District 8 (see appendix B.2, figure 7.1 and figure 7.2). These new flooded areas show that the road elevations can not protected for the low lands in all the urban zones at the tide level 1.85m.



	IND-T1	IND-T2	IND-T3	IND-T4	IND-T5	PUB-T1	PUB-T2	PUB-T3	PUB-T4	PUB-T5	RES-T1	RES-T2	RES-T3	RES-T4	RES-T5
Tide level 1.50m (ha)	13	120	145	151	597	15	78	93	87	271	134	734	814	880	1369
Tide level 1.85m (ha)	34	150	272	716	1141	26	93	155	181	639	112	932	1202	1761	4756

Fig. 7.7: Flooded areas of built up types at tide levels in flooding duration grades in Ho Chi Minh City

As shown in figure 7.7, the resident land use type is the land use type that has the most flooded area of the build up land use. Flooded area distribution of the type is similar to the other types because the tide characteristic impacts to flooding duration so that the most flooded area of the type is still grade 5 and the least is grade 1. However there is some difference of the flooded area at the flooding duration grades. The difference is a narrow variation of the flooded area between the grades. At the tide level 1.50m the flooded area at the grade 5 holds on 35%, at the grade 1 is 3% and the other grades are around 20%. The reason is the resident land use type is distributed in the relative high lands and variation of elevation in the type is small in the regions. Besides the resident regions are located in the low lands are protected by roads so that at this tide level there is not extremely differences at the grades. However these constructions are not distributed regular for all urban zones therefore distribution of the flooded area in the urban zones is not the same. In the rural and new urban almost flooded area concentrates at the grade 5 but in the old center urban the flooded area at all grades is same (see appendix B.2). This information shows that the resident regions in the rural and new urban are located in the low lands but there is not many constructions that can help to protect the region prevention of inundation. To assess more clearly, the flooded area data at the tide level 1.85m can answer. When tide level rises to 1.85m, almost flooded area at the grades is increase exceptional that does grade 1. Moreover, the higher grade is the more flooded area increased. The most increasing of the flooded area is grade 5 with 3.5 times as many as that does at tide level 1.50m. The explanation for this phenomenon is there are not much more the high land resident regions in all the urban zones to flood when tide level rises. Only the low lands which are protected by the roads but the roads can not help to prevent the regions inundation at the high tide so that the low lands are flooded for long duration. In the rural the low lands are extended for inundation is Binh Chanh Rural District and Nha Be Rural District. In the new urban that is Binh Tan District, Thu Duc District, District 2, District 7 and District 12. And in the old center urban that are District 4, District 6, District 8 and Binh Thanh District. One general reason is the flooded areas at all grades at tide level 1.50m are moved to the grade 5 at tide level 1.85m so that the number of the flooded area at the grade 5 increases more than the others (see appendix B.2, figure 7.1 and figure 7.2).

3.4. Frequency grades

The result of the flooded area for all land use types at the grades of the flooding frequency is shown in table 7.6 and chart in the figure 7.8. In the general, all the land use types are flooded at all the flooding frequency grades at two tide levels. Additionally, the information in the table shows a rule of the flooded area that the flooded area at two tide levels has the grade 1 and grade 4 more than that does the grade 2 and grade 3. The reason is tide characteristic as tide value range for the grade 2 and grade 3 is shorter than that does for grade 1 and grade 4 (see appendix A.2). As a result, probability of the land is flooded at the grade 2 and grade 3 is lower than that does at the grade 1 and grade 4. Moreover, the largest value range is the grade 4 so that the flooded area at the grade 4 is the most, less is grade 1, much less is grade 2 and the least is grade 3 for all the land use types. Another general conclusion is flooded area of each of the land use types is increased when tide level rises from 1.50m to 1.85m.

For the industry land use type, at the tide level 1.50m the flooded area is concentrated at the grade 4 with 55%, the flooded area holds on at the grade 1 with 27%, the least is the grade 3 with 8% and the rest is grade 2 with 10%. The first reason is tide characteristic that is tide value range for the grade 4 and grade 1 is larger than the others. The second reason is the industry regions are developed newly and located in the low land of the rural and new urban regions so that the flooded area of this type makes up a lot of area impacted at the grade 4. Therefore there is difference of flooded area between grade 1 and grade 4 (see appendix B.3, figure 7.2 and figure 7.3). At the tide level 1.85m, flooded area at all grades is increased. The increasing flooded area at the grade 2 is the most and a few less is grade 4. The reason is the new flooded area of the industry type in the rural such as in the Binh Chanh Rural District and Cu Chi Rural District, and the new urban such as District 7, Thu Duc District and Binh Tan District at the tide level 1.50m are protected by roads, however the road elevations can not help these regions to prevent inundation at the tide level 1.85m. However, the roads help for the flooding frequency in the regions reduces fairly (see appendix B.3, figure 7.1 and figure 7.2).

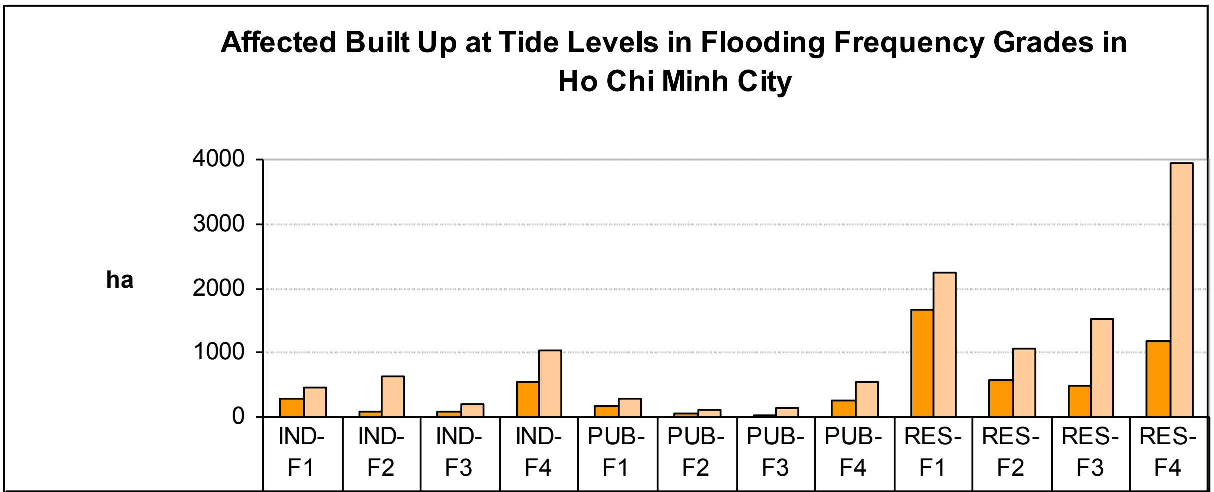
In a general trend, for the open space land use type, the flooded area still concentrates the most in the highest grade of the flooding frequency. At the tide level 1.50m the most flooded area is at the grade 4 holds on 69%. The second is grade 1 holds on 13% but the flooded area at the grade 1 is not much more than that does grade 2 and grade 3. Besides the general reason is the tide characteristic, another reason is open space land use type is distributed in the lowest regions of Ho Chi Minh City so that the flooded area at the grade 4 is occupied much more the others. When the tide level rises to 1.85m, the flooded area at the grade 4 is still increased and reached to 72%. The other grades are changed with the different amount. The flooded area at the grade 1 and grade 2 is decreased because there is not much high land to be inundated. As shown in the appendix A.2, the flooded area at all grades at tide level 1.50m are moved to the grade 4 at tide level 1.85m so that the number of the flooded area at the grade 4 holds on more than the others. Besides the new flooded areas are low lands in rice – crop fields of Binh Chanh Rural District, Nha Be Rural District and forest in Can Gio Rural District and these areas are protected by roads as tide level 1.50m but the road elevations are not much higher than 1.50m so that at tide level 1.85m the areas are inundated at the high grades of the flooding frequency (see appendix B.3, figure 7.1 and figure 7.2).

For the public land use type, there is always a priority of this land use type when planners make land use planning. This type is disposed in the higher lands of districts. As a result, the flooded area is less than the other land use types. For the flooding frequency, the flooded area distribution at the grades has similar to the other build up types with the most flooded area is grade 4, the second is grade 1 and much less is grade 2 and grade 3. This show at the tide level 1.50m, the most flooded area at the grade 4 still makes up 48%, the second is grade 1 with 34%, and the third is grade 2 with 12% and the least is grade 3 with 6% as much as total flooded area at the tide level 1.50m. The reasons are similar with the other land use types. The most flooded area at the grade 4 is distributed in the new urban in District 2 and Nha Be Rural District because there are some new harbors constructed and developed here. And in these regions almost area is low terrain so that the flooded area is inundated much more appearances. The major portion of the flooded area at the grade 1 is the old center urban in Binh Thanh District and Go Vap District and one of portion in the new urban in District 7. These regions are low lands but they are protected by roads so that the appearance of the inundation is reduced. As a result these regions almost area is flooded at the grade 1. The flooded area distribution of the public land use type at tide level 1.85m is similar to tide level 1.50m. The most flooded area is still grade 4 and grade 1. However, there is increasing of flooded area at grade 2 and grade 3. About absolute value of the flooded area, when the tide level raises to 1.85m all the grades of flooding frequency are increased area. The absolute values of change the flooded area is increased the most at the grade 4 with 285ha and grade 3 with 113ha. However, the speed up the new flooded area is grade 3 with 4.2 times as much as at tide level 1.50m. The reason is at the tide level 1.50m the flooded area at the grade 3 is less than the grade 4 so that the speed up the new flooded area at the grade 3 more than the grade 4. In the all urban zones the flooded area of the public type is extended. In the rural the flooded area is extended in Binh Chanh Rural District, Can Gio Rural District, Nha Be Rural District and Hoc Mon Rural District. In the new urban the flooded area is increased in Thu Duc District, Binh Tan District, District 7 and District 12. In the other urban zone, the flooded area is added in District 4, District 6, and District 8 (see appendix B.3, figure 7.1 and figure 7.2). These new flooded areas show that the road elevations can not protected for the low lands in all the urban zones at the tide level 1.85m.

Tab. 7.6: Flooded areas of built up types at the tide levels in flooding frequency grades in Ho Chi Minh City

No	Land Uses	Frequency	Code	Flooded Areas			
				TL 1.50m		TL 1.85m	
				ha	%	ha	%
1	Industry	Less 1 t/m (ha)	IND-F1	278	0.5	457	0.5
2	Industry	1 - 3 t/m (ha)	IND-F2	101	0.2	625	0.7
3	Industry	3 - 7 t/m (ha)	IND-F3	87	0.1	206	0.2
4	Industry	More 7 t/m (ha)	IND-F4	560	0.9	1,025	1.2
5	Open Space	Less 1 t/m (ha)	OSP-F1	7,425	12.3	9,209	10.4
6	Open Space	1 - 3 t/m (ha)	OSP-F2	4,391	7.3	4,111	4.6
7	Open Space	3 - 7 t/m (ha)	OSP-F3	5,851	9.7	8,188	9.2
8	Open Space	More 7 t/m (ha)	OSP-F4	37,364	61.7	55,021	62.0
9	Public	Less 1 t/m (ha)	PUB-F1	187	0.3	274	0.3
10	Public	1 - 3 t/m (ha)	PUB-F2	63	0.1	126	0.1
11	Public	3 - 7 t/m (ha)	PUB-F3	35	0.1	149	0.2
12	Public	More 7 t/m (ha)	PUB-F4	260	0.4	545	0.6
13	Resident	Less 1 t/m (ha)	RES-F1	1,683	2.8	2,246	2.5
14	Resident	1 - 3 t/m (ha)	RES-F2	579	1.0	1,057	1.2
15	Resident	3 - 7 t/m (ha)	RES-F3	495	0.8	1,529	1.7
16	Resident	More 7 t/m (ha)	RES-F4	1,175	1.9	3,932	4.4
Total				60,533	100.0	88,700	100.0

As shown in figure 7.8, the resident land use type is the land use type that has the most flooded area of the build up land use and impacts to inhabitants living in the city. Flooded area distribution of the type is similar to the other types because the tide characteristic impacts to flooding frequency so that the most flooded area of the type is still grade 4 and the least is grade 1. However there is some difference of the flooded area at the flooding frequency grades. The difference is a narrow variation of the flooded area between the grades. At the tide level 1.50m there is a change that is the flooded area at the grade 1 is more than that does at the grade 4. In the ordinal of reducing flooded area, the grade 1 holds on 43%, the grade 4 is 30%, the grade 2 is 15% and the least is grade 3 with 12%. The reason is the resident land use type is distributed in the relative high lands and variation of elevation in the type is small in the regions. Besides the resident regions are located in the low lands are protected by roads so that at this tide level there is not extremely differences at the grades. However these constructions are not distributed regular for all urban zones therefore distribution of the flooded area in the urban zones is not the same. In the rural and new urban almost flooded area concentrates at the grade 4 and grade 1 with the same number of the flooded area but in the old center urban the flooded area holds on the most at the grade 1 and the other grades is very little including the least flooded area is grade 4 (see appendix B.3). This information shows that the resident regions in the rural and new urban are located in the low lands but there is not many constructions that can help to protect the region for prevention of inundation as in the old center urban.



	IND-F1	IND-F2	IND-F3	IND-F4	PUB-F1	PUB-F2	PUB-F3	PUB-F4	RES-F1	RES-F2	RES-F3	RES-F4
Tide level 1.50m (ha)	278	101	87	560	187	63	35	260	1683	579	495	1175
Tide level 1.85m (ha)	457	625	206	1025	274	126	149	545	2246	1057	1529	3932

Fig. 7.8: Flooded areas of built up types at tide levels in flooding frequency grades in Ho Chi Minh City

To assess more clearly, the flooded area data at the tide level 1.85m can answer. When tide level raises to 1.85m, almost flooded area at all the grades is increase. The most increasing of the flooded area is grade 3 with 3.1 times and grade 4 with 3.5 times as many as that does at tide level 1.50m. The explanation for this phenomenon is there are not much more the high land resident regions in all the urban zones to flood when tide level rises. Only the low lands which are protected by the roads but the roads can not help to prevent the regions inundation at the high tide so that the low lands are flooded for long duration. In the rural the low lands are extended for inundation is Binh Chanh Rural District and Nha Be Rural District. In the new urban that is Binh

Tan District, Thu Duc District, District 2, District 7 and District 12. And in the old center urban that are District 4, District 6, District 8 and Binh Thanh District. One general reason is the flooded areas at all grades at tide level 1.50m are moved to the grade 5 at tide level 1.85m so that the number of the flooded area at the grade 5 increases more than the others (see appendix B.3, figure 7.1 and figure 7.2).

Chapter 8. Conclusion and Recommendation

1. Conclusions

Nowadays, climate change is an issue that has a very large scope with affecting many aspects of human society. In Ho Chi Minh City the impact of the climate change influences to human by severe consequences that cause rising sea level so that there are a lot of flood risk to development of the city in the future. Therefore, this research aims another approach to assess flood risk by the application of GIS in improving the accuracy of the inputs for flood model and reducing time cost.

As mentioned in the research aims and objectives, there are two major aims for this research. The first aim is applying GIS to improve the accuracy of data input for a flood model besides using this technology to compute the other characteristics of flood caused by high tide in Ho Chi Minh City. The second one is to determine qualitative information of the elements of urban system effectively by GIS so that the result can be captured rapidly and be useful for decision makers and planners for development in Ho Chi Minh City in the future.

The archives of the research are summarized in the next sections of this chapter. Besides, each section is also make remarks that research has not yet reached to improve in future further researches.

1.1. Flood model and flooded areas in Ho Chi Minh City

This is part that addresses conclusions of the targets and remarks of the first objective in the research. The objective relates to improving the precision of the digital terrain model that is one of the important inputs to the flood model and moreover a calculation of flooding characteristics that are caused by tide levels from the flood model based on GIS.

- This research has proposed a new method to increase the accuracy of terrain that is one of the most important inputs of any flood model. The terrain is simulated in the digital terrain model with providing for elevations of roads, houses and irrigation networks. This is really important when running flood model in urban areas because the terrain surface is more accurate so that its results make the more accurate floodplain.

- Giving a specific approach for determining the frequency and duration of tidal flooding was caused by tide combining sea level rise. This determining makes many advantages in assessing the flood risk as well as helping for more comprehensive assessment of the flood risk.
- When the tide level rises, the flooded area is increased much in all urban zones and high risk grades of flooding characteristics.
- The flooded areas increase from urban zones to new urban zones and the highest in rural zones. The flooded areas are concentrated in the southern and eastern regions of the city at both tide levels 1.50m and 1.85m.
- Many areas are not flooded at tide level 1.50m but they are not sustainable due to they are protected by the roads that have elevation to be not much higher than 1.50m. So when the tide reaches to 1.85m a lot of these areas are inundated seriously.
- As the tide level rises, the flooded areas of the high depth grades hold on major that can make human damage and affect more inhabitants living in the flooded areas.
- Almost areas are flooded for longer than 4 hours. This requires special attention due to the flood impact to works of the inhabitants in especial problems of environment, health and income.
- Flooding frequency of almost flooded areas is more than 7 time per month. And more risk when the tide level increases, the urban areas are regions where have increase of flooded areas with high flooding frequency. This is against convenient life of the inhabitants who are living there.

There is a remark that is due to the problem in collecting observed data is missed so that the flood model was not able to calibrate and verify. And so, the flooded areas will make a trend to be larger. That means flood prone areas and their impacts are more than that is in reality.

Another thing is the elements of uncertainty of the factors influencing to flood risk in the future. The first element is the climate change. This is one of the forecast scenarios of emission that shows population development and technology used in the future on over the world. The second factor is the change in the structures of the urban system such as traffic, land use… that influent to flood processes. Moreover the second one leads to the third element of uncertainty that is changed topography of the city. The reason of the element is any locations where are used for development of urban the ground surfaces in there will be impacted a lot of terrain height.

1.2. Flood risk of houses

Houses are the one of objects that is main interested goal for assessment of the flood risk in the research. For houses, the research has come up with data that can use to assess the flood risk on all flooding characteristics. Moreover, it also analyzes the areas where houses are impacted in the different grades of the flooding characteristics. The archives of the research are detailed as shown below:

- Although flooded areas increase gradually from old center urban to the rural but the flooded houses do opposite direction at the tide levels. And there is more dangerous that is the most areas are flooded in the old center urban at the high tide level. This is a notice for the inhabitant living.

- Almost houses are flooded areas but they are only affected that mean no water is inside of the houses. However, the tide level 1.85m there are many houses sunk in the water of flood and the flooded house areas are increased rapidly. This arise problems of environment, health and income for the inhabitants.

- All the urban zones in the city are increased flooded area of the 0 - 0.5m deep at the tide level 1.85m so that there should be more attention of the authorities and inhabitants. An essential of delivering information and announcements that can help to improve understanding for the inhabitants in the low lands of the flood risk in future should be carried out for adaptation.

- As the tide level increases, flooded houses at the high grades of flooding duration are extended a lot. That means the risk is promoted so that living activities of the inhabitants are more and more impacted.
- Flooded house areas at the high grades of flooding frequency are increased the most in the old center urban and new urban. This shows that the protective structures with the roads are not really sustainable to help the low land prevented flood by high tide in the future.
- For flooding frequency, at the tide level 1.50m almost flooded house areas are low grades but at the tide level 1.85m flooded house areas at the highest grade are increased very seriously besides extension of flooded areas at the others grades does. And more interesting that is the flooded house areas at the highest grade are developed rapidly in the old center urban and new urban where population density is very high. Consequently this impacts to living activities of inhabitants a lot in the future.

There is a remark for the calculation result data of the houses. The remark concerns the problem of asynchronous time of existing data that are collected in this study. The elevation points are extracted from aerial photos captured older than house data. Therefore, this can also lead to the calculation that is not perfect on the results. However, a forecast result of the flood risk in the future that can use to predict risks for the development in Ho Chi Minh City is useful entirely for the planning and orientation in the study area.

1.3. Flood risk of population

Inhabitants are the most important object that the research is interested for assessment of the flood risk. For population, the research has come up with data that can use to assess the flood risk on all flooding characteristics. Moreover, it also analyzes the areas where inhabitants are impacted in the different grades of the flooding characteristics. The archives of the research are detailed as shown below:

- There is a large number of flooded inhabitants is increased 2.5 times as many as that does when tide level rises from 1.50m to 1.85m.
- Number of the flooded inhabitants is increased gradually from the rural to the old center urban at the two tide levels. The reason is amount of flooded

house areas also occur the same situation and additionally the population density does as well.

- About flooding depth, almost inhabitants are impacted by flooded at the lowest grade and the number of affected inhabitants is decreased gradually with the higher grades at two tide levels. However, when the tide level rises, the number inhabitants of the higher grades of the flooding depth are more increased. This is a matter that makes more dangerous for the inhabitants in the future.

- The amount of affected inhabitants in the urban zones is impacted differently. The most dangerous concentrates in the rural and the new urban as tide level rises. In these urban zones there is a number of affected inhabitants is more increased than that is in the old center urban when tide level rises. The cause is in the rural and new urban have a lot of the lowest land in Ho Chi Minh City and besides the population is raised day by day. This makes a notice that the authority should have a warnings about the flood risk in the future to the inhabitants who are living and would move to live in these zones.

- Amount of inhabitants at the flooding duration grades at the tide level 1.50m is not different but at the tide level 1.85m the amount of inhabitants is increased gradually risk grades of the flooding duration. Additionally, when tide level raises amount of affected inhabitants is increased at almost the flooding duration grades but increasing strongly at the high grades. It is a notice for insurance of economic activities of the inhabitants.

- The number of the affected inhabitants at the grades of the flooding duration in all urban zones when the tide level rises is increased. The most increasing is the old center urban and concentrated at the longest flooding duration. The increasing is reduced gradually from the old center urban to the rural. This means in the future the low lands in the old center urban will be flooded longer than the other urban zones and so that activities of inhabitant living there will be impacted more and more.

- When the tide level is low almost the inhabitants are impacted by flood with less than 1 time per month and the flooded area at the high frequency grades is not much and equal to each of the others. However, when tide level raises to 1.85m the number of the affected inhabitants is increased rapidly. And the more dangerous the flooded area is held on the more strongly that is increased. This concludes that in the future there are a lot of the inhabitants are impacted more serious because the number of flooding frequency is speeded up.

- Moreover, the number of flooding frequency is increased in all urban zones and the increasing trend more than in the old center urban and less than in the rural. In the future there are a lot of regions in the old center urban are inundated with high flooding frequency so that with the high population density, number of affected inhabitants with more than 7 times/month in these regions is increased 10 times as much as at tide level 1.50m. This is serious problem that needs to resolve as soon as possible. If there is not a suitable solution there are a lot of environmental troubles that impact to inhabitant health, income and other activities of their life.

There is a remark for the calculation result data of the population. The remark concerns the problem of asynchronous time of existing data that are collected in this study. Besides the elevation points are extracted from aerial photos captured older than house data, the house data are also older than population data. Therefore, this can also lead to the calculation that is not perfect on the results. However, a forecast result of the flood risk in the future that can use to predict risks for the development in Ho Chi Minh City is useful entirely for the planning and orientation in the study area.

1.4. Flood risk of land use

The final object is interested in the research is land use. This object relates to urban system of the region. Therefore assessment of the flood risk is necessary for this research. For land-use types, the research has come up with data that can use to assess the flood risk on all flooding characteristics. Moreover, it also analyzes the areas where the land use types are impacted in the different grades of the flooding characteristics. The archives of the research are detailed as shown below:

- Almost flooded area is open space land use type because the open space type is distributed in the lowest regions which are located in southern and eastern Ho Chi Minh City with the forest and rice – crop fields. In the build up land use types, the resident type is flooded the most at two tide levels. When tide level rises, all land use types are increased flooded area. For the industry type is almost flooded area in the rural and new urban because policies requires industry regions must be located further from the old center urban therefore there are almost old industry and new industry parks that must move to the rural or new urban nowadays. For the public land use type the flooded area is the new urban because there are some new harbors in the District 2 and District 7 are inundated. With the resident land use type at the tide level 1.50m there is not much difference of the flooded area in each of the urban zones but at the tide level 1.85m there are a lot of new flooded area in the old center urban and new urban because many regions in these urban zones are protected by roads at low tide level but they can not protect at tide level 1.85m.

- About flooding depth impact to land use types, all land use types have almost flooded area is not much deep at two tide levels. However, number of the flooded area that is inundated deep at the tide level 1.85m is increased. This conclusion issues a warning for preparation to adapt with more flood impact in the future. Distribution of the land use types in the different urban zones is not the same and there is not a general trend for all land use types in the flooding depth.

- In the contrast to characteristic of the flooding depth, in the flooding duration all land use types have a trend that is the higher grade is the more flooded area concentrates at two tide levels. And when tide level raises, almost the grades of flooding duration, flooded area of all land use types is increased in different degrees. And a special notice is the most increasing of the flooded area is the highest grade of the flooding duration. This means the income and works of the inhabitants living in the flooded area will be impacted more serious by the flooding duration characteristic. Distribution of the flooded area in the urban zones of the flooding duration characteristic is not followed any rule for all land use types. For the industry and open space types the change of the flooded area in the urban zones as tide level raises is not clear. And for the public and resident types the flooded area at all flooding duration grades is increased almost urban zones.

- All land use types have flooded area at all flooding frequency grades. The most flooded area is the highest grade with more than 7 times per month. When tide level raises almost flooded area of the land use types is increased. The most increasing of the flooded area is the highest grade. This is again that reminds there is more attention of the flood impact to inhabitants living activities in the flooded regions. For the different land use types in each of the urban zones, increasing of the flooded area is not similar to each of others. Industry and open space land use types are extended mostly new flooded area in the rural. Otherwise, the public and resident land use types, the new flooded area is increased nearly equally in all the urban zones.

There is a remark for the calculation result data of the land use types. Similarly to houses and population, the remark concerns the problem of asynchronous time of existing data that are collected in this study. Besides the elevation points are extracted from aerial photos captured older than land use types. Therefore, this can also lead to the calculation that is not perfect on the results. However, a forecast result of the flood risk in the future that can use to predict risks for the development in Ho Chi Minh City is useful entirely for the planning and orientation in the study area.

2. Recommendations

Each research can only meet some specific goals. And this research is not an exception. Therefore, the results of this research will be useful data for policy makers and planners to make development plans in the future for Ho Chi Minh City. Besides, the research results are the foundation data to address directions of further applied researches in the human social aspects affected by flood risk. Therefore, this part of the thesis provides some suggestions for decision makers and researchers who are able to conduct and create much more results that can be applied wider other fields that help Ho Chi Minh City to be able to develop more sustainable in the future.

2.1. Authorities and decision makers

For the authorities and decision makers who make the policies, regulations and decisions in Ho Chi Minh City, the research recommends some suggestions that help for reducing of impacts of flood by sea level rise in the future to social economic development. Additionally, beyond researches should be projected based on the results of the research so that more policies and regulations improve the suitable and sustainable development in Ho Chi Minh City in the future under climate change especially with sea level rise:

- Need further researches on flood impacts to the social economic fields and based on those results, the authorities deliver policies that can support for groups of people who are impacted and help them to improve resistibility to flood risk in the future.
- Enhance construction management to minimize spontaneous urbanization by inhabitants in the flooded potential areas. Consequently, there is at least the flood risk when the sea level will rise in the future for human and properties.
- The local government should conduct a research to build guide lines to help inhabitants who are living in the flooded areas adaptations behaviors when the sea level rises in the future.

2.2. Planner

The planners are one of the user groups from the results of the research because planning is to lead and orient direction of the development in a region. Therefore, with the forecast results of this research about flood risk in the future in Ho Chi Minh City, the author of the research has some suggestions to the planners as followings:

- Should make a plan of land use that moves the developing urban areas to west northern and east northern regions. Reducing and make low residential density in the low land regions where are able to flood in the future.
- Research and suggest land use types that are adaptable for the flooded areas.

- Research and suggest house types that can adapt and be reliable in the flooded areas.
- Construct guide lines that instruct for inhabitants living in the flooded areas to be able to build their houses which are secure and resilient with flood in the future.

2.3. Outlooks and further researches

As shown in the results of the research, some results can be used directly to policy makers and planners. However, society is a system of human aspects, so with limited time and resources, the research certainly can not cover all the fields to what influence the flood risk. Therefore, research results that should be used as a based one to conduct further researches on other fields in Ho Chi Minh City to serve more sustainable development are to continue. Some directions of the further researches should be studied extension based on this research as mentioned following:

- The research has defined and calculated the flooding duration characteristic causing by tide in the flood model. However, the flooding characteristic is only right when the flooded areas are not barrier to flow back as tide is decreased. For the others terrain with closing or small out let that has gate to discharge volume of water equal to the tide decreasing real flooding duration will be longer than value of the flooding duration is calculated by the flood model in the research. Therefore consideration of this problem should be improved in the further study to make the reliable and stable value of the flooding characteristic.
- Improve more for the data accuracy especially for terrain data with the river bed data so that it is helpful for applying advance flood models such as 2D, Couple 1D and 2D… to determine the flood characteristics. Those results will be better and more accurate.
- Applying the flood models that can implement set of flood causes such as tide combine with rainfall and discharge from upstream reservoirs. This will make the results that are more real situations.
- Should be more attention with the land subsidence phenomenon to flood problem. Nowadays, there are a lot of evidences that show the land

subsidence in Ho Chi Minh City is appearing with high speed and perhaps the land subsidence is more than sea level rise (Dinh et al., 2008; Nga, 2006; Trung, 2009; Trung & Dinh, 2009). Therefore, the land subsidence is not mention in the flood problem in the future so that the research results of the flood problem are not accurate to use in the reality.

- Make more study about impacts of the dike system for flood problem when it is rain. This situation has a high probability of appearance because tide and rainfall come together at the same time. And if the dike system protects flood caused by tide but the system also blocks the water flow so that the flood will appear. Therefore, a demand for understanding of water volume from the rainfall in the situation and that is helpful for authorities to prepare resources to face with the situation such as build more pumping stations, control lakes and reservoirs in the areas where are accumulation flow from rainfall.

Appendixes

Appendix A.1: Tide peaks and their duration (hour) at levels 1.50m and 1.85m

Duration (hour)	H_150 (cm)	H_185 (cm)	Duration (hour)	H_150 (cm)	H_185 (cm)
4.28	115	150	2.82	133	168
4.21	116	151	2.73	134	169
4.14	117	152	2.64	135	170
4.07	118	153	2.55	136	171
4.00	119	154	2.46	137	172
3.93	120	155	2.37	138	173
3.86	121	156	2.28	139	174
3.79	122	157	2.16	140	175
3.72	123	158	2.04	141	176
3.63	124	159	1.92	142	177
3.54	125	160	1.80	143	178
3.45	126	161	1.68	144	179
3.36	127	162	1.57	145	180
3.27	128	163	1.45	146	181
3.18	129	164	1.33	147	182
3.09	130	165	1.21	148	183
3.00	131	166	1.09	149	184
2.91	132	167	0.00	150	185

Appendix A.2: Tide peaks and their frequency (time/month) at levels 1.50m and 1.85m

H_150 (cm)	H_185 (cm)	Frequency (times/month)	H_150 (cm)	H_185 (cm)	Frequency (times/month)
115	150	7.233	133	168	0.608
116	151	6.454	134	169	0.492
117	152	5.825	135	170	0.396
118	153	5.188	136	171	0.317
119	154	4.667	137	172	0.246
120	155	4.146	138	173	0.204
121	156	3.692	139	174	0.150
122	157	3.250	140	175	0.108
123	158	2.900	141	176	0.079
124	159	2.538	142	177	0.054
125	160	2.213	143	178	0.038
126	161	1.913	144	179	0.017
127	162	1.696	145	180	0.013
128	163	1.475	146	181	0.008
129	164	1.292	147	182	0.008
130	165	1.104	148	183	0.004
131	166	0.917	149	184	0.004
132	167	0.767	150	185	0.004

Appendix B.1: Land use types at flooding depth grades in urban zones of Ho Chi Minh City

No	Land Uses	Urban zones	Depth	Code	Flooded Areas (ha)	
					1.50m	1.85m
1	Industry	New Urban	0 - 0.5m	INDNUR1	190.4	538.5
2	Industry	Rural	0 - 0.5m	INDRUR1	219.1	243.9
3	Industry	Old Center Urban	0 - 0.5m	INDURB1	133.1	210.3
4	Industry	New Urban	0.5 - 1.2m	INDNUR2	86.2	340.5
5	Industry	Rural	0.5 - 1.2m	INDRUR2	371.9	555.9
6	Industry	Old Center Urban	0.5 - 1.2m	INDURB2	14.5	102.0
7	Industry	New Urban	1.2 - 1.8m	INDNUR3	3.8	85.5
8	Industry	Rural	1.2 - 1.8m	INDRUR3	6.2	233.4
9	Industry	Old Center Urban	1.2 - 1.8m	INDURB3	0	3.2
10	Industry	New Urban	Deeper 1.8m	INDNUR4	0	0.1
11	Industry	Rural	Deeper 1.8m	INDRUR4	0	0.4
12	Open Space	New Urban	0 - 0.5m	OSPNUR1	2,224.8	1,416.6
13	Open Space	Rural	0 - 0.5m	OSPRUR1	23,100.7	12,633.2
14	Open Space	Old Center Urban	0 - 0.5m	OSPURB1	278.6	218.2
15	Open Space	New Urban	0.5 - 1.2m	OSPNUR2	5,759.0	5,916.4
16	Open Space	Rural	0.5 - 1.2m	OSPRUR2	22,560.6	40,627.5
17	Open Space	Old Center Urban	0.5 - 1.2m	OSPURB2	155.8	524.0
18	Open Space	New Urban	1.2 - 1.8m	OSPNUR3	231.7	3,081.0
19	Open Space	Rural	1.2 - 1.8m	OSPRUR3	6,93.0	11,747.9
20	Open Space	Old Center Urban	1.2 - 1.8m	OSPURB3	1.2	222.7
21	Open Space	New Urban	Deeper 1.8m	OSPNUR4	0.6	13.4
22	Open Space	Rural	Deeper 1.8m	OSPRUR4	25.5	128.8
23	Open Space	Old Center Urban	Deeper 1.8m	OSPURB4	0	0
24	Public	New Urban	0 - 0.5m	PUBNUR1	133.0	242.6
25	Public	Rural	0 - 0.5m	PUBRUR1	85.8	117.1

26	Public	Old Center Urban	0 - 0.5m	PUBURB1	100.0	172.9
27	Public	New Urban	0.5 - 1.2m	PUBNUR2	126.1	184.6
28	Public	Rural	0.5 - 1.2m	PUBRUR2	60.1	173.5
29	Public	Old Center Urban	0.5 - 1.2m	PUBURB2	27.2	95.8
30	Public	New Urban	1.2 - 1.8m	PUBNUR3	6.9	49.6
31	Public	Rural	1.2 - 1.8m	PUBRUR3	4.3	42.3
32	Public	Old Center Urban	1.2 - 1.8m	PUBURB3	1.2	12.8
33	Public	New Urban	Deeper 1.8m	PUBNUR4	0	1.8
34	Public	Rural	Deeper 1.8m	PUBRUR4	0	0.3
35	Resident	New Urban	0 - 0.5m	RESNUR1	981.5	1,353.8
36	Resident	Rural	0 - 0.5m	RESRUR1	1,023.5	1,327.2
37	Resident	Old Center Urban	0 - 0.5m	RESURB1	1,058.8	1,572.7
38	Resident	New Urban	0.5 - 1.2m	RESNUR2	335.9	1,219.2
39	Resident	Rural	0.5 - 1.2m	RESRUR2	392.3	1,764.9
40	Resident	Old Center Urban	0.5 - 1.2m	RESURB2	115.4	817.0
41	Resident	New Urban	1.2 - 1.8m	RESNUR3	19.0	376.1
42	Resident	Rural	1.2 - 1.8m	RESRUR3	3.7	309.5
43	Resident	Old Center Urban	1.2 - 1.8m	RESURB3	1.4	19.1
44	Resident	New Urban	Deeper 1.8m	RESNUR4	0	3.3
45	Resident	Rural	Deeper 1.8m	RESRUR4	0	0.5
46	Resident	Old Center Urban	Deeper 1.8m	RESURB4	0	0

Appendix B. 2: Land Use Types in Flooding Duration grades in urban zones of Ho Chi Minh City

No	Land Uses	Urban zones	Duration	Initial	Flooded Areas (ha)	
					1.50m	1.85m
1	Industry	New Urban	< 1 hour	INDNUR1	5.3	29.0
2	Industry	New Urban	1 - 2 hours	INDNUR2	44.0	87.3
3	Industry	New Urban	2 - 3 hours	INDNUR3	60.4	171.1
4	Industry	New Urban	3 - 4 hours	INDNUR4	45.4	327.5
5	Industry	New Urban	> 4 hours	INDNUR5	125.3	349.7
6	Industry	Rural	< 1 hour	INDRUR1	4.3	1.5
7	Industry	Rural	1 - 2 hours	INDRUR2	45.8	21.6
8	Industry	Rural	2 - 3 hours	INDRUR3	42.5	54.6
9	Industry	Rural	3 - 4 hours	INDRUR4	68.4	330.4
10	Industry	Rural	> 4 hours	INDRUR5	436.1	625.4
11	Industry	Old Center Urban	< 1 hour	INDURB1	3.0	3.9
12	Industry	Old Center Urban	1 - 2 hours	INDURB2	30.6	41.5
13	Industry	Old Center Urban	2 - 3 hours	INDURB3	41.6	46.5
14	Industry	Old Center Urban	3 - 4 hours	INDURB4	36.9	58.0
15	Industry	Old Center Urban	> 4 hours	INDURB5	35.6	165.7
16	Open Space	New Urban	< 1 hour	OSPNUR1	46.1	94.1
17	Open Space	New Urban	1 - 2 hours	OSPNUR2	240.8	253.9
18	Open Space	New Urban	2 - 3 hours	OSPNUR3	389.9	655.1
19	Open Space	New Urban	3 - 4 hours	OSPNUR4	582.0	920.0
20	Open Space	New Urban	> 4 hours	OSPNUR5	6,957.4	8,504.4
21	Open Space	Rural	< 1 hour	OSPRUR1	356.9	73.6
22	Open Space	Rural	1 - 2 hours	OSPRUR2	2,290.8	4,539.0
23	Open Space	Rural	2 - 3 hours	OSPRUR3	4,014.5	3,498.7
24	Open Space	Rural	3 - 4 hours	OSPRUR4	6,919.0	6,805.5
25	Open Space	Rural	> 4 hours	OSPRUR5	32,798.4	50,220.6
26	Open Space	Old Center Urban	< 1 hour	OSPURB1	3.1	3.5
27	Open Space	Old Center Urban	1 - 2 hours	OSPURB2	29.2	41.1
28	Open Space	Old Center Urban	2 - 3 hours	OSPURB3	53.8	50.4

29	Open Space	Old Center Urban	3 - 4 hours	OSPURB4	125.6	201.4
30	Open Space	Old Center Urban	> 4 hours	OSPURB5	223.9	668.6
31	Public	New Urban	< 1 hour	PUBNUR1	6.0	18.0
32	Public	New Urban	1 - 2 hours	PUBNUR2	36.6	35.8
33	Public	New Urban	2 - 3 hours	PUBNUR3	34.2	69.8
34	Public	New Urban	3 - 4 hours	PUBNUR4	38.0	63.4
35	Public	New Urban	> 4 hours	PUBNUR5	151.2	291.6
36	Public	Rural	< 1 hour	PUBRUR1	4.0	1.2
37	Public	Rural	1 - 2 hours	PUBRUR2	17.3	20.2
38	Public	Rural	2 - 3 hours	PUBRUR3	29.0	49.9
39	Public	Rural	3 - 4 hours	PUBRUR4	21.8	69.8
40	Public	Rural	> 4 hours	PUBRUR5	78.0	192.1
41	Public	Old Center Urban	< 1 hour	PUBURB1	5.3	6.7
42	Public	Old Center Urban	1 - 2 hours	PUBURB2	24.5	36.9
43	Public	Old Center Urban	2 - 3 hours	PUBURB3	29.8	35.1
44	Public	Old Center Urban	3 - 4 hours	PUBURB4	26.7	47.3
45	Public	Old Center Urban	> 4 hours	PUBURB5	42.2	155.6
46	Resident	New Urban	< 1 hour	RESNUR1	69.4	80.0
47	Resident	New Urban	1 - 2 hours	RESNUR2	220.7	320.5
48	Resident	New Urban	2 - 3 hours	RESNUR3	252.1	607.3
49	Resident	New Urban	3 - 4 hours	RESNUR4	306.2	390.7
50	Resident	New Urban	> 4 hours	RESNUR5	488.1	1,554.0
51	Resident	Rural	< 1 hour	RESRUR1	30.4	13.7
52	Resident	Rural	1 - 2 hours	RESRUR2	218.6	375.2
53	Resident	Rural	2 - 3 hours	RESRUR3	262.2	293.9
54	Resident	Rural	3 - 4 hours	RESRUR4	282.0	854.5
55	Resident	Rural	> 4 hours	RESRUR5	626.2	1,864.9
56	Resident	Old Center Urban	< 1 hour	RESURB1	34.4	18.2
57	Resident	Old Center Urban	1 - 2 hours	RESURB2	295.1	236.8
58	Resident	Old Center Urban	2 - 3 hours	RESURB3	300.0	300.8
59	Resident	Old Center Urban	3 - 4 hours	RESURB4	291.9	515.7
60	Resident	Old Center Urban	> 4 hours	RESURB5	254.3	1,337.4

Appendix B. 3: Land use types at flooding frequency grades in urban zones of Ho Chi Minh City

No	Land Uses	Urban zones	Frequency	Code	Flooded Areas (ha)	
					1.50m	1.85m
1	Industry	New Urban	< 1 t/m	INDNURF1	109.7	287.4
2	Industry	New Urban	1 - 3 t/m	INDNURF2	28.9	291.9
3	Industry	New Urban	3 - 7 t/m	INDNURF3	26.432	104.9
4	Industry	New Urban	> 7 t/m	INDNURF4	115.3	280.4
5	Industry	Rural	< 1 t/m	INDRURF1	92.7	77.7
6	Industry	Rural	1 - 3 t/m	INDRURF2	45.7	298.8
7	Industry	Rural	3 - 7 t/m	INDRURF3	36.9	59.8
8	Industry	Rural	> 7 t/m	INDRURF4	421.9	597.2
9	Industry	Old Center Urban	< 1 t/m	INDURBF1	75.2	91.9
10	Industry	Old Center Urban	1 - 3 t/m	INDURBF2	26.0	34.5
11	Industry	Old Center Urban	3 - 7 t/m	INDURBF3	23.2	41.5
12	Industry	Old Center Urban	> 7 t/m	INDURBF4	23.3	147.7
13	Open Space	New Urban	< 1 t/m	OSPNURF1	676.8	1,003.2
14	Open Space	New Urban	1 - 3 t/m	OSPNURF2	379.7	779.2
15	Open Space	New Urban	3 - 7 t/m	OSPNURF3	402.7	429.0
16	Open Space	New Urban	> 7 t/m	OSPNURF4	6,757.0	8,216.1
17	Open Space	Rural	< 1 t/m	OSPRURF1	6,662.3	8,111.2
18	Open Space	Rural	1 - 3 t/m	OSPRURF2	3,935.7	3,204.8
19	Open Space	Rural	3 - 7 t/m	OSPRURF3	5,371.0	7,451.5
20	Open Space	Rural	> 7 t/m	OSPRURF4	30,410.6	46,369.8
21	Open Space	Old Center Urban	< 1 t/m	OSPURBF1	86.1	95.0
22	Open Space	Old Center Urban	1 - 3 t/m	OSPURBF2	75.8	127.1
23	Open Space	Old Center Urban	3 - 7 t/m	OSPURBF3	77.1	307.3
24	Open Space	Old Center Urban	> 7 t/m	OSPURBF4	196.5	435.6
25	Public	New Urban	< 1 t/m	PUBNURF1	76.8	123.6
26	Public	New Urban	1 - 3 t/m	PUBNURF2	28.7	45.9

27	Public	New Urban	3 - 7 t/m	PUBNURF3	15.3	43.1
28	Public	New Urban	> 7 t/m	PUBNURF4	145.3	266.0
29	Public	Rural	< 1 t/m	PUBRURF1	50.3	71.3
30	Public	Rural	1 - 3 t/m	PUBRURF2	16.1	44.0
31	Public	Rural	3 - 7 t/m	PUBRURF3	8.3	67.7
32	Public	Rural	> 7 t/m	PUBRURF4	75.5	150.2
33	Public	Old Center Urban	< 1 t/m	PUBURBF1	59.5	78.6
34	Public	Old Center Urban	1 - 3 t/m	PUBURBF2	18.4	36.6
35	Public	Old Center Urban	3 - 7 t/m	PUBURBF3	11.7	37.9
36	Public	Old Center Urban	> 7 t/m	PUBURBF4	38.8	128.4
37	Resident	New Urban	< 1 t/m	RESNURF1	542.2	1,007.7
38	Resident	New Urban	1 - 3 t/m	RESNURF2	176.9	246.9
39	Resident	New Urban	3 - 7 t/m	RESNURF3	190.6	361.4
40	Resident	New Urban	> 7 t/m	RESNURF4	426.8	1,336.4
41	Resident	Rural	< 1 t/m	RESRURF1	511.2	682.7
42	Resident	Rural	1 - 3 t/m	RESRURF2	176.3	456.7
43	Resident	Rural	3 - 7 t/m	RESRURF3	177.1	843.2
44	Resident	Rural	> 7 t/m	RESRURF4	554.8	1,419.4
45	Resident	Old Center Urban	< 1 t/m	RESURBF1	629.4	555.8
46	Resident	Old Center Urban	1 - 3 t/m	RESURBF2	225.5	353.4
47	Resident	Old Center Urban	3 - 7 t/m	RESURBF3	127.5	324.0
48	Resident	Old Center Urban	> 7 t/m	RESURBF4	193.2	1,175.7

Appendix C: Land use classes transferred from UST

UST Code	UST Description	Land Use Code	Land use Description
610	High dense	IND	Industry
611	Industry high dense sealed yard	IND	Industry
612	Industry high dense unsealed yard	IND	Industry
620-	Low dense	IND	Industry
621	Industry low dense sealed yard	IND	Industry
622	Industry low dense unsealed yard	IND	Industry
125	Irregular Shophouse with large gardens/fields (peri-urban)	OSP	Open Space
710	Park	OSP	Open Space
711	Forested park	OSP	Open Space
712	Mixed park	OSP	Open Space
720	Harvested crops	OSP	Open Space
721	Water paddy	OSP	Open Space
722	Remaining water paddy	OSP	Open Space
723	Agroforestry	OSP	Open Space
724	Other annual crops	OSP	Open Space
725	Other agricultural use	OSP	Open Space
726	Other food crops	OSP	Open Space
727	Other perennial crops	OSP	Open Space
728	Irrigated land	OSP	Open Space
729	Urban commercial agricultural service	OSP	Open Space
730	Aquaculture	OSP	Open Space
731	Brine and sea aquaculture	OSP	Open Space
732	Freshwater aquaculture	OSP	Open Space
740	Forest	OSP	Open Space
741	Special use forest	OSP	Open Space
742	Protected natural forest	OSP	Open Space

743	Designated area for protective forest	OSP	Open Space
744	Planted protective forest	OSP	Open Space
745	Orchard plantation	OSP	Open Space
746	Designated land for reforestation of protective forest	OSP	Open Space
747	Designated area for reforestation of productive forest	OSP	Open Space
748	Land including planted production forest	OSP	Open Space
750	Open land	OSP	Open Space
751	Planted grassland	OSP	Open Space
752	Natural grassland	OSP	Open Space
753	Unused land	OSP	Open Space
754	Under construction	OSP	Open Space
760	Waste disposal and treatment site	OSP	Open Space
761	Municipal solid waste site	OSP	Open Space
762	Wastewater treatment plant	OSP	Open Space
770	Sport site	OSP	Open Space
771	Sport site grass	OSP	Open Space
772	Sport site sealed	OSP	Open Space
773	Stadium	OSP	Open Space
780	Cemetery	OSP	Open Space
790	Surface water	OSP	Open Space
791	Surface water for specific use	OSP	Open Space
792	Pond/Lake	OSP	Open Space
793	Water course	OSP	Open Space
510	Education	PUB	Public
511	Campus	PUB	Public
512	High-dense	PUB	Public
520	Centres of trade and commerce	PUB	Public
521	Traditional covered market stalls	PUB	Public
522	Shopping centre	PUB	Public

530	Place of worship	PUB	Public
531	Religious and worship site	PUB	Public
532	Site traditional beliefs	PUB	Public
540	Hospital and health centre	PUB	Public
550	Administration and public offices	PUB	Public
560	Transport nodes	PUB	Public
561	Bus station	PUB	Public
562	Train station	PUB	Public
563	Airport/ heliport	PUB	Public
564	Port passenger	PUB	Public
565	Port container	PUB	Public
566	Parking	PUB	Public
570	Cultural arts theatre/Museum	PUB	Public
571	Land used by offices and non profit	PUB	Public
572	Place of cultural arts	PUB	Public
573	Historical heritage site	PUB	Public
580	Energy and communication infrastructure	PUB	Public
581	Energy infrastructure	PUB	Public
582	Communication infrastructure	PUB	Public
590	Security and military	PUB	Public
591	Military area	PUB	Public
592	Security site	PUB	Public
111	Shophouse regular new	RES	Resident
112	Shophouse regular new community	RES	Resident
113	Shophouse regular with narrow street/alleyways	RES	Resident
114	Shophouse regular with yards	RES	Resident
121	Shophouse irregular highdense	RES	Resident
122	Shophouse irregular with yards	RES	Resident
123	Irregular shophouse scattered (peri-urban)	RES	Resident
124	Irregular shophouse clustered/Linear (peri-urban)	RES	Resident

126	Shophouse irregular temporary	RES	Resident
131	Shophouse with industry	RES	Resident
132	Shophouse irregular with regular	RES	Resident
211	Villa	RES	Resident
212	Luxury villa	RES	Resident
213	Gated villa community	RES	Resident
221	Villa in establish UST	RES	Resident
231	Colonial villa	RES	Resident
311	Lowrise apartment < 9 floors	RES	Resident
312	Highrise apartment > 9 floors	RES	Resident
321	Chinese apartment	RES	Resident
322	American apartment	RES	Resident
323	Social housing	RES	Resident
411	Central business district	RES	Resident
412	Central business district with highrise	RES	Resident

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