Wu, Tingyeh; Takara, Kaoru

The Establishment and Discuss of the Vulnerability Assessment for Flood Risk

ESTABLISHMENT OF VULNERABILITY ASSESSMENT FRAMEWORK FOR TYPHOON DISASTERS

Tingyeh WU[1], Kaoru TAKARA[2]

[1] Doctoral student, Department of Urban and Environment Engineering, Kyoto University
Nishikyo-ku, Kyoto, 615-8540, Japan, e-mail: tingyeh.w@kt4.ecs.kyoto-u.ac.jp
[2] Professor, Disaster Prevention Research Institute, Kyoto University
Gokasho, Uji-shi, Kyoto, 611-0011, Japan, e-mail: takara@flood.dpri.kyoto-u.ac.jp

ABSTRACT

This paper describes the relationships between exposure, hazard mapping, and vulnerability analysis, and represents the initial vulnerability assessment results for the typhoon disasters. Based on different scales, vulnerability can be divided into five layers. Several connections of these five layers, the levels of vulnerability are defined, as vulnerability of the community, local government, and central government. On the other hand, a simple concept of the cost and benefit analysis is used to evaluate the efficiency of the mitigation program.

Keywords: vulnerability, mitigation, benefit, the comprehensive emergency management program

1. INTRODUCTION

Natural hazards bring the disasters happen which always results in the enormous loss, especially in recent years. In order to decrease the loss, governments start to take focus on engineering and non-engineering treatments. The comprehensive emergency management program (The CEM program) mentioned by Federal Emergency Management Agency (FEMA) is a systematic program includes many treatments held in a continuous procedure before, during, and after disasters happen. There are four main procedures contained in the CEM program, which are response, recovery, preparedness, and mitigation. The main proposes of the strategies and policies designed and held in the four procedures by governments are to prevent and decrease the serious loss happens. However, the loss occurs or not depends on not only how the efficiency the strategies or the policies is, but also how the natural conditions that the community or the elements distributed in the hazardous area are. However, the discussion on the efficiency of the mitigation program is not much referred in the related studies.

The importance of vulnerability is now a major concern in disaster mitigation. It has been found that factors that lead to disasters, not only include destructive natural hazards, but also vulnerability factors, such as environmental and social aspects, and human activities. The definition made by United Nations in the International Strategy for Disaster Reduction (ISDR, 2004) is representative, which is that vulnerability is a set of conditions and processes resulting from physical, social, economical, and environmental factors that increase the susceptibility of a community to the impact of hazards. Several extended models cited this definition. Wisner et al. (1994) mentioned that vulnerability is generated for economic, social and political processes. Turner II et al. (2003) evaluated vulnerability from exposure, sensitivity, and resilience. Bohle (2001) divided vulnerability into internal and external parts, the internal part being the ability to cope with the hazard; the external part being the exposure to risk and shocks.

Some of the definitions and methodologies proposed an ambiguous concept that vulnerability is limited to one time scale and one element or community. However, it is apparent that vulnerability changes with the time or with different levels, although there are few studies that mention this. Consequently, the first part of this study clarifies framework of vulnerability and indicates the relationship of its parts, and the second part describes a simple method to evaluate the efficiency of the CEM program.

2. THE DESTRUCTIVE DISASTERS

Two typhoons occurred in Taiwan in 2004 were considered in this study, which are Typhoon Mindulle and Typhoon Aere. The two typhoons are the most serious typhoons in the recent 20 years. Typhoon Mindulle occurred in June 29th, the accumulated precipitation during the typhoon exceeded 2000 mm. Most of the precipitation fell in the mountainous area, which resulted in the serious sediment disasters in the middle and south parts of Taiwan. In this disaster, 29 people dead, 12 missing, and 16 injured, the estimated loss is more than 500 million dollars. Typhoon Aere occurred in August 23rd, the accumulated precipitation during the typhoon exceeded 1500 mm. Most of precipitation fell in the north and west parts of Taiwan, and resulted in the severe landslide disaster. The damage of the typhoon event is 14 people dead, with 15 missing, and 395 injured, the estimated loss is about 67 million dollars.

3. THE VULNERABILITY FRAMEWORK

Based on the definition referred to in many studies (see Sec. 1), the risk for natural hazards is the interaction of hazard and vulnerability, which can be described as the probability of the harmful event, including the loss of the life, persons injured, property damaged, and economic activity disrupted. The harmful event in this case is limited to sediment disasters in the consideration of risk of the natural hazard. Therefore, hazard pertains to one sediment event, and was used in a limited sense; a hazard is defined as the range and frequency of the historical event.

On the other hand, we accept the definition of vulnerability made by ISDR (2004), although we consider that it should be explained further. Based on Birkmann (2007), vulnerability can be explained as several layers at different scales (Fig. 1).

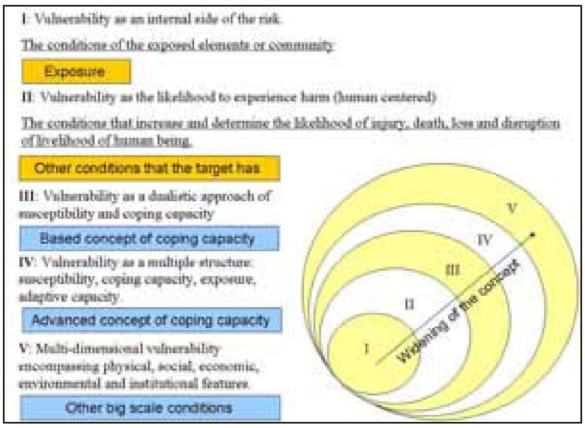


Figure 1 The concept of vulnerability (modified from Birkmann, 2007)

The first layer is the core level, which indicates conditions of the exposed element or community. The second layer includes the conditions that increase or decrease the probability of the harmful event. We define this as the other condition that the vulnerability level can lead to loss. Factors generated from layers 1 and 2 are connected to the vulnerability level of community or groups, which suffer by natural hazards directly. The risk assessment in this study also considers the assessment of the community vulnerability level.

The layer 3 is the dualistic approach of susceptibility and coping capacity. The latter includes the basic infrastructure and equipment that are able to support or be located in the community. In the layer 4, the vulnerability includes the multiple factors, such as susceptibility, coping capacity, exposure, and adaptive capacity. We define it as the advanced concept of coping capacity which includes the engineering and non-engineering strategies. Because the local government tends to supervise the mitigation activities and the rescue operations, we generalize the vulnerability level for the local government as layer 4. The layer 5 contains all large scale factors in the vulnerability, including political, environmental, ecological, and institutional factors. Generally, the central government leads the mitigation program and landuse program. Therefore, this is viewed as the vulnerability of the central government.

The main concern in our framework is limited to the central government and local government. Any mitigation program conceived by governments must decrease the loss in these areas. This is shown in Figure 2, containing the vulnerability for the local and central governments.

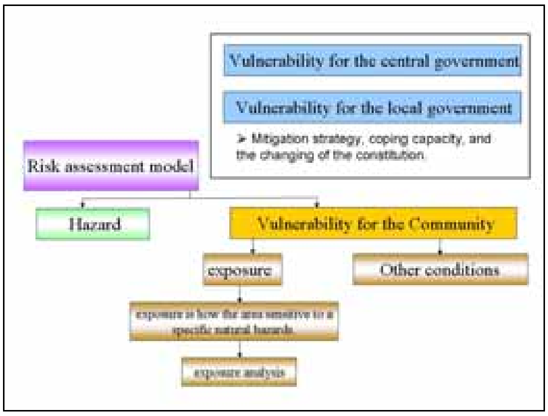


Figure 2 The framework of the vulnerability

The vulnerability for the small areas, containing community or village, some of the factors are considered to contribute it, such as exposure and other conditions, including economical or social conditions. On the other hand, a hazard is a potential for physical events, phenomena, or human activities, which may cause the loss and can be shown by location, intensity, and probability (ISDR, 2004). Historical data can be used to represent the probability and magnitude of a hazard. Alternatively, hazard maps can be generated based on risk assessment models to traditionally show estimates of the same probability and magnitude. However, risk is the function of vulnerability and hazard. We see in Fig. 2 that exposure, which is how sensitive an area is to a natural hazard, is a factor in vulnerability. Therefore, similar to the probability that we associate to a natural hazard, exposure can be quantified as a probability. We can thus evaluate this probability of exposure via methods normally performed for hazard mapping.

4. METHODOLOGY

4.1 THE FLOOD STRATEGIES IN THE CEM PROGRAM

To consider how the governments supervise the mitigation program, the concept of the comprehensive emergency management program (the CEM program) procedures were used in this study. The strategies held for mitigation could be corresponded to Mitigation, Preparedness, Recovery, and Response of the CEM program based on the emergency manual.

According to the four procedures in the CEM program, we connected the strategies held before, during, and after disaster happen with the four procedures (Table 1). The mitigation is decided as the tangible strategies in this study, because it contains engineering strategies, the preparation and supervision of the equipment. On the other hand, the Preparedness includes the strategies for designing and planning the mitigation resources or collecting the data for announcing or forecasting. Hence, it is decided as the intangible strategies. The Recovery is the strategies held for recovering the destroyed part during or after disasters, including the recovery of the lifeline, roadway, and engineering facilities. The Response is the respondent and operations when the disaster happens. However, it is ignored in this study because of the assumption that the cost for the Response did not include in the CEM program.

Table 1 The strategies in the CEM program

Procedure	Strategies	Description
Mitigation	Engineering strategies, Supervise the land-use, Basic equipment preparedness	Tangible strategies
Preparedness	Designing and planning the mitigation resources during the disasters, and data collection.	Intangible strategies
Recovery	Strategies held during or after disasters happen in order to recover the destroyed part.	Recovery
Response	Strategies and operations held when the disasters happen.	-

4.2 THE GOVERNING STATEMENT

To estimate the cost and benefit of the CEM program, firstly, clarifying the relationships between the items of the CEM program is necessary, there is a basic concept of the government is willing to pay for the CEM program used (Ko, 2004). It is shown in formula (1),

$$L_{be}P_{be} - L_{af}P_{af} \geq C \quad \textbf{(1)}$$

Where L_{be} is the loss happens before the mitigation program, L_{af} is the loss happens after the mitigation program, P_{be} and P_{af} are the probability of the natural hazard, C is the cost for the CEM program.

In the study, we assumed that the probability of the natural hazard is the same, which means that P_{be} equals to P_{af}. Therefore, from the formula 1, we can get a relationship between the decrease of the loss (L_{be} - L_{af}), the cost for the mitigation (C), and the probability (P), which is shown in formula 2,

$$P(L_{be} - L_{af}) \geq C \quad \textbf{(2)}$$

From formula 2, the minimum cost that the government is willing to pay for the mitigation program equals to the product of the probability and the decrease of the loss. It also means that the benefit of the mitigation program is how much loss decreased between two disasters. It is also the ratio of *C* and *P*.

On the other hand, we considered several items occur between two disasters, including Loss, Recovery, Mitigation, and Preparedness (Figure 3). Because of assuming that there are no severe disasters happen before the first disaster, it could be convinced that no any strategies or policies applied for decreasing the risk of the natural hazards. Based on the assumption, we could understand two important remarks. Firstly, there are no Loss, Recovery, Mitigation, and Preparedness before the first disaster. Secondly, The cost for the CEM program could be calculated according to the function of the *C* and the ratio of *P* and *L*. Especially, the cost for the first CEM program is the product of probability and loss happened after the first disaster.

According to the Figure 3, the relationship between Loss, Recovery (*R*), Mitigation (*Mi*), Preparedness (*P*), and Cost for the CEM program (*Cost*) is described as formula (3),

$$Mi + P = Cost + Loss + R \quad \textbf{(3)}$$

Proposes of the CEM program are to recover the situation from disaster and increase the ability to cope with the attacking of the natural hazards. Therefore, it is thought that the sum of the mitigation and preparedness is equal to the sum of the money pay for the CEM program, the loss in the disaster, and the money paid for recovery.

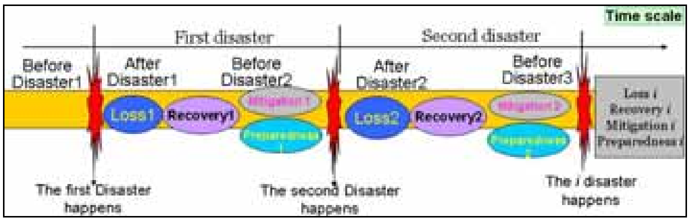


Figure 3 The relationship of items in CEM program between disasters

5. RESULTS AND CONCLUSION

Table 2 shows the calculation results. Firstly, the cost of the CEM program is calculated according to the disaster probability and the loss. Secondly, the sum of the Mitigation and Preparedness was evaluated based on the loss, Recovery, and the cost of the CEM program. In the typhoon Minulle, the sum of the Mitigation and Preparedness is 728 million dollars, and in the typhoon Aere, the sum of the Mitigation and Preparedness is 166 million dollars. The amount of the price means the money is paid on engineering and non-engineering strategies. After comparing to the result, it is apparently that the amount of money paid for increasing the mitigation ability decreased. Between the two typhoon events, the decreased price is about 562 million dollars. This finding matches with the assumption that the cost for mitigation decreases after each disasters.

On the other hand, the loss decreases after the second disaster, which is about 478 million dollars. It can be seen as the benefit of the mitigation strategies after the first disaster. In other words, the mitigation cost for the first disaster has a benefit of 478 million dollars because the loss decreased in the second disaster. On the other hand, it is easily to evaluate the price paid for intangible strategies if the cost for tangible strategies is known. The result in the study is the initial one, it is necessary to have more disaster events data to prove and improve the model.

Table 2 The calculation result of the CEM program

		Mindulle	Aere
Disaster probabiltiy		200 years	200 years
Loss (dollars)		546,602,818	67,974,606
	Engineering facilities	307,948,000	50,517,515
	Public infrastructure	139,342,606	6,915,273
	Building	2,823,970	0
	Agraiculture loss	96,342,788	10,447,879
	Dead, and injured	145,455	93,939
	Dead (person)	32	14
	Disappear (person)	13	15
	Injured (person)	20	395
The cost of the CEM		2,733,014	2,393,141
Recovery (dollars)		178,969,121	95,691,424
	recovery when emergency	14,398,333	17,420,727
	recovery after the disaster(engineering facilities)	161,685,455	76,776,636
	recovery after the disaster(public infrastructure)	2,885,333	1,494,061
Mitigation Preparedness (dollars)		728,304,953	166,059,171

In this study we define a vulnerability framework and show a simple method to evaluate and represent the efficiency of the strategies held for the CEM project, which can be summarized as follows,

1. According to the studies cited in this study, we find that the aspects that the vulnerability contains based on different levels, which are vulnerability for the central and local governments and community in the vulnerability framework.
2. To estimate the vulnerability for central and local governments, a simple formula was used. Based on the formula, the relationship between the items in the CEM program could be shown easily and the amount of the money paid for tangible and intangible strategies could be estimated, as well.
3. From the result of the calculation, it proved that the amount of money paid for Mitigation and Preparedness decreased in the second disaster, which is about 562 million dollars. The decreasing of the loss also represents the benefit of the mitigation program held after the first disaster.

ACKNOWLEDGE

The authors would like to thank the National Fire Agency, Ministry of the Interior for applying the typhoons damage data and the emergency manual.

REFERENCES

Birkmann, J. (2007), Measuring Vulnerability to Natural Hazards: Towards Disaster Resilient Societies, United Nations University.

Ko, Y. C. and Chen, S. C. (2004), The position of "Designated soil and water conservation area" in national land-use planning, *Journal of Chinese soil and water conservation*, 35(4): 309-322 (in Chinese).

International Strategy for Disaster Reduction (ISDR), (2004), Living with the risk─ A global review of disaster reduction initiatives, United Nations.

Wamsler, C. (2006), Mainstreaming risk reduction in urban planning and housing: a challenge for international aid organizations, *Disasters*, 30(2): 151-177.

Influence of Storm Surges on the Inundated Potential in the Coastland

Meng-Hsuan Wu[1], Ching-Nuo Chen[2], Chih-Heng Tsai[3] and Chang-Tai Tsai[4]

[1] Ph.D. student, Department of Hydraulics and Ocean Engineering, National Cheng-Kung University
No.1, University Road, Tainan 70101, Taiwan, e-mail: n8893105@mail.ncku.edu.tw
[2] Post-Doctor, Department of Hydraulics and Ocean Engineering, National Cheng-Kung University
No.1, University Road, Tainan 70101, Taiwan, e-mail: cnchen@mail.hyd.ncku.edu.tw
[3]Assistant Professor, Department of Resources and Environment, Leader University
No.188, Sec. 5, Anjhong Rd., Annan District, Tainan City 709, Taiwan, e-mail: jht@mail.hyd.ncku.edu.tw
[4] Professor, Department of Hydraulics and Ocean Engineering, National Cheng-Kung University
No.1, University Road, Tainan 70101, Taiwan, e-mail: htct@mail.ncku.edu.tw

ABSTRACT

Storm surges do not only affect the capacity of drainage system but also lead to serious inundation damages in the coastland. The basin of the Jiangjyun river is used as an illustrative example in this study. The Physiographic Drainage - Inundation model is applied to evaluate the inundated potential for a historical typhoon event and twelve designed heavy-rains with the conditions for storm surges and astronomical tides as different individual conditions. The influence of the storm surge on the inundated potential in the basin of the Jiangjyun river is investigated by the simulation of above cases for inundated potential. The results obtained for the case of the surge storm for inundated potential simulation are compared with those for the astronomical tide. The simulated results obtained from inundated potential reveals that inundated potential in the coastland in terms of the inundation depth and area for the case of the surge storm are plainly greater than those for the astronomical tide. Therefore, it is crucial to consider the influence of storm surges when planning the scale of drainage systems and dikes in the coastland.

Keywords: storm surge, inundated potential, inundation depth, inundation area, climate changes

1. INTRODUCTION

Due to the development of economy, increasing population, and transportation infrastructure of the coastland, drainage system and land uses have been changed for decades in Taiwan. These changes along with groundwater over-pumping lead to not only the increase of surface runoff but also the acuteness of land subsidence. The retarding effect of roads might alter the basin boundary of the drainage. This effect induces the overbasin flow which can also exceed the capacity of the present drainage system. Therefore, there is a special need to evaluate the current drainage system and the influence of these changes.

In addition to physical changes, we need to pay additional attention on extreme hydrological events due to climate changes. These extreme hydrological events include storms, super typhoons, and astronomical tides. Especially, super typhoons often bring heavy rain as well as rise the sea level because of the barometric depression. Therefore, these extreme hydrological events may further strike the drainage system and increase the damage of inundation. This study applies the Physiographic Drainage - Inundation model to evaluate the inundated potential in the coastland in terms of the inundation depth and area, and to estimate the influence of the storm surge on the inundated potential in the coastland.

The basin of the Jiangjyun river is used as an illustrative example in this study. The

Physiographic Drainage - Inundation model is applied to simulate the inundated scenarios for a historical typhoon event and twelve designed heavy-rains with the conditions for storm surges and astronomical tides as different individual conditions. The influence of the storm surge on the inundated potential in the basin of the Jiangjyun river is investigated by the simulation of above cases for inundated potential.

2. PHYSIOGRAPHIC DRAINAGE - INUNDATION MODEL

The computed cells in accordance with the landscape and drainage network of the watershed are automatically generated in the Physiographic Drainage - Inundation model. The water flow calculation uses the Physiographic Drainage - Inundation model, which is based on the continuity equation and discharge theory in each cell. The continuity equation for water flow is given (Yang, 2000).

$$As_i \frac{dh_i}{dt} = Pe_i + \sum_k Q_{i,k}\left(h_i, h_k\right) \tag{1}$$

where As_i = the area of the i-th cell; h_i = water depth in the i-th cell; t = time; $Q_{i,k}$ = the discharge from the k-th cell, which is the adjacent cell of the i-th cell, into the i-th cell; Pe_i = the effective rainfall intensity multiplied by the area of the i-th cell. The $Q_{i,k}$ in Eq 1 can be represented by any appropriate discharge formula as described below.

2.1 Channel-Linked Discharge Formula

Selection flow conditions for the flow between cells without obvious obstacles can be treated as an idealized channel flow and the discharge can be calculated by the Manning formula (Yang and Tsai, 1997). The discharge can be calculated by Eq.2 and Eq. 3.

$$\frac{\partial Q_{i,k}}{\partial h_i} < 0\,,\;\; Q_{i,k} = \frac{h_k - h_i}{\left|h_k - h_i\right|} \cdot \Phi(\bar{h}_{i,k}) \cdot \sqrt{\left|h_k - h_i\right|} \tag{2}$$

$$\frac{\partial Q_{i,k}}{\partial h_i} > 0\,,\;\; Q_{i,k} = \Phi(\bar{h}_{i,k}) \cdot \sqrt{\left|h_k - h_i\right|} \tag{3}$$

where $\bar{h}_{i,k}$ = the water stage from the k-th and i-th cells, is given as:

$$\bar{h}_{i,k} = \alpha h_k + (1-\alpha) h_i \tag{4}$$

where α = an weighting-coefficient; Φ = the flow parameter, defined as $\Phi(h) = \frac{\frac{1}{n} A R^{2/3}}{\sqrt{\Delta x}}$.

where Δx = the distance of the canter between the k-th and i-th cells; n =the Manning's roughness coefficient of the cells; A = the cross-sectional flow area between the k-th and i-th cells, $A = A(\bar{h}_{i,k})$; R = the hydraulic radius between the k-th and i-th cells, $R = R(\bar{h}_{i,k})$.

2.2 Weir-Linked Discharge Formula

On the other hand, for the adjacent cell divided by roads or hydraulic structures, the flow over them can be treated as the weir flow. The discharge can be calculated by Eq.5 and Eq. 6.

For a free over weir, $(h_i - Z_w) < \frac{2}{3}(h_k - Z_w)$

$$Q_{i,k} = \Phi_f (h_k - Z_w)^{3/2}, \ \ \Phi_f = \mu_1 b\sqrt{2g} \tag{5}$$

For a submerged weir, $(h_i - Z_w) \geq \frac{2}{3}(h_k - Z_w)$

$$Q_{i,k} = \Phi_d (h_i - Z_w)(h_k - h_i)^{1/2}, \ \ \Phi_d = \mu_2 b\sqrt{2g} \tag{6}$$

where Z_w = the elevation of the weir crest; b = the effective width of the weir; μ_1 and μ_2 = the weir discharge coefficients, μ_1 = 0.37~0.57 and μ_2 = 2.6 μ_1.

Therefore, the explicit finite-difference representation of Eq. 1 can be written as

$$\Delta h_i = [Pe_i + \sum Q_{i,k}(h \ , h_k)]\Delta t / A_{si} \tag{7}$$

where As_i , Pe_i ,and $Q_{i,k}$ are the area, rainfall intensity of the i-th cell and the discharge from the k-th cell into the i-th cell at t ; Δt is the time step of t to $t + \Delta t$; Δh_i is the i-th cell increment of water stage in a time step.

3. STUDY AREA

The basin of the Jiangjyun river is used as an illustrative example in this study. The lagoon of the lowland plain and hill along the coast from the south of the Bajhang river to the north of the Zengwun river was selected as the study area for investigating the inundation phenomena of the basin of the Jiangjyun river. In addition to the Jiangjyun river, the study area also contains the Jishuei and Cigu rivers. The area of the Jiangjyun river basin is about 158.4 square kilometer and the length of the main stream is about 28 kilometer. The basin of the Jiangjyun river in the study area is shown in Figure 1.

ArcGIS™ software - ArcView® and ArcInfo® - are adopted in this study to analyze DEM, slope, and pool of the study site. Information of roads, drainage ditches, and land use are also included in the GIS database. The entire basin was divided into 6,626 irregular grids (as shown in Figure 2) by automatic modeling-cell-delimitation method that used the spatial analyst, hydrologic model, and Object-oriented Programming of ArcView. All attributes of data fields were also calculated to build the necessary database for Physiographic Drainage - Inundation model.

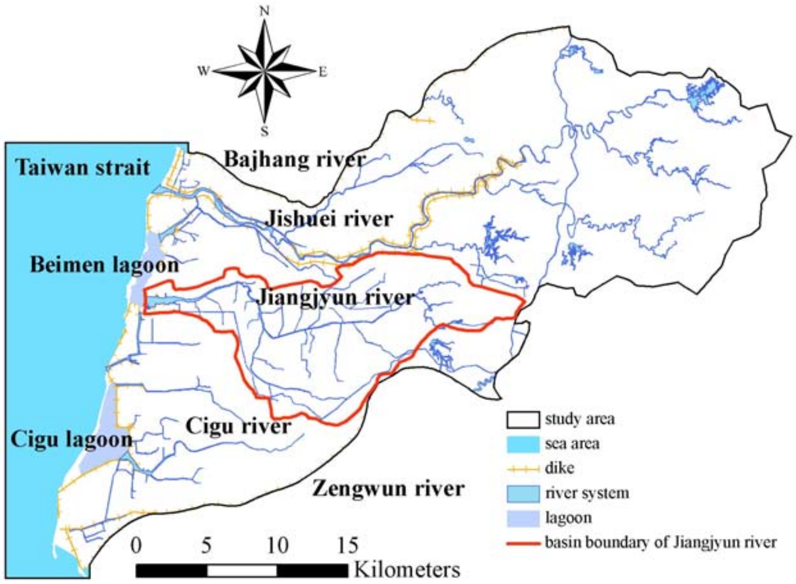


Figure 1 The basin of the Jiangjyun river in the study area

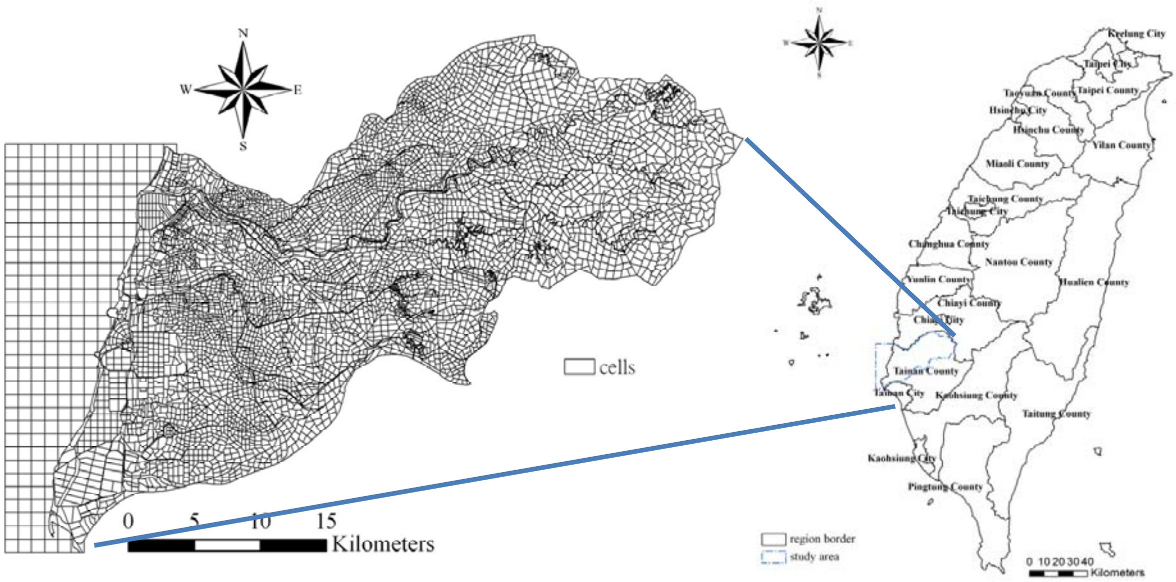


Figure 2 Construction of cells in the study area

4. RESULTS AND DISCUSSIONS

The basin of the Jiangjyun river is used as an illustrative example in this study. Based on the physiographic properties of the Jiangjyun river basin, GIS system is applied to construct the cells of the study area automatically. The hydrologic parameters and the physiographic parameters of each cell are obtained from above analyses. The Physiographic Drainage - Inundation model is applied to simulate the inundated scenarios for twelve designed heavy-rains with the tidal conditions for storm surges and astronomical tides as different individual conditions. Thus, the influence of the storm surge on the inundated potential in the basin of the Jiangjyun river is investigated by the simulation of the above cases for inundated potential.

4.1 Hydrologic Data

In order to test and verify the physiographic Drainage - Inundation model, the results of simulation of the historical typhoon event are compared with observation and investigation in the field. Floods are caused by twelve designed heavy-rains with different durations and return periods obtained from frequency analysis and storm pattern analysis. Influence of storm surges on the inundated potential in the coastland was investigated by simulating floods caused by twelve designed heavy-rains.

The study area was divided into several control areas of the rain gage stations by utilizing the Thiessen polygons method. In this study, the rainfall data of each rain gage station for each cell were utilized to simulate the phenomena of the historical typhoon.

Distribution and control areas of the rain gage stations possessed by the Central Weather Bureau were shown in Figure 3. The rainfall data of the rain gage stations in study area and the adjacent area were utilized to proceed frequency analysis and storm pattern analysis. Floods are caused by twelve designed heavy-rains with different durations and return periods obtained from the results of frequency analysis and storm pattern analysis.

The tide levels in the coastland of the historical typhoon were obtained from the historical data of the Jiangjyun tidal gauge station. The tide levels in the coastland of the twelve were obtained from the results of the analyses of astronomical tide and surge deviation. The results of the tidal analysis were shown in Figure 4.

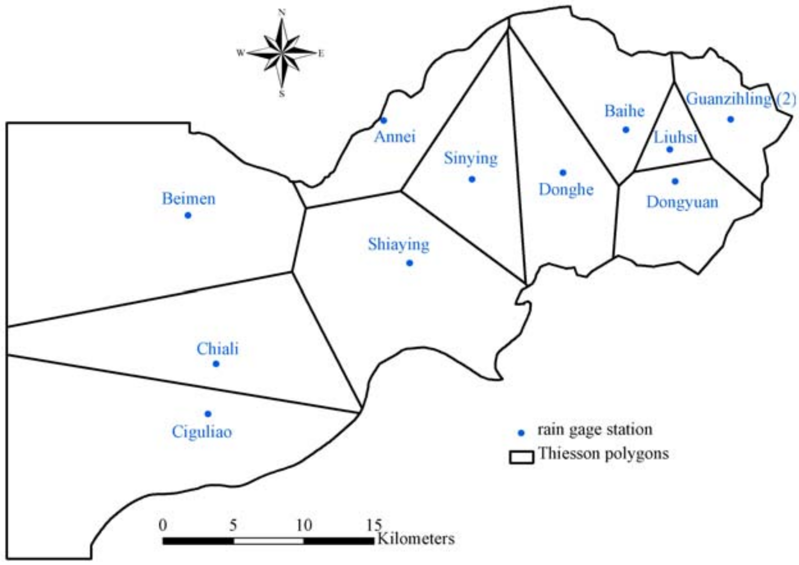
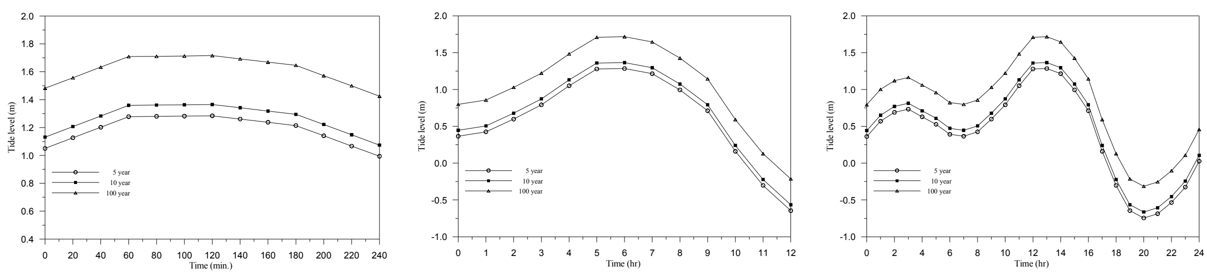


Figure 3 Thiesson polygons in the study area



4 hour duration of rainfall　　12 hour duration of rainfall　　24 hour duration of rainfall

Figure 4 Tidal boundary condition for the case of designed heavy-rains (in meter)

4.2 Simulation for a Historical Typhoon Event

Typhoon Haitang, which occurred in 2005 to cause serious inundated damages in the basin of the Jiangjyun river, was utilized as an illustrative example. The maximum inundated depth based on the simulations was shown in Figure 5. Further, the result of simulation of Typhoon Haitang is compared with observation and investigation in the field (Water Hazard Mitigation Center, Water Resources Agency, MOEA, 2007) in order to test and verify the physiographic Drainage - Inundation model. The simulated results contain the inundation depth, area, and so on. The results of observation and investigating in the field were shown in Figure 6.

Based on the comparison of simulated results with the observed data shown in Figures 5 and 6 individually, the simulated results obtained from inundating potential reveals that inundated potential in the coastland in terms of the inundation depth and area are coincident with the results of observation and investigation in the field.

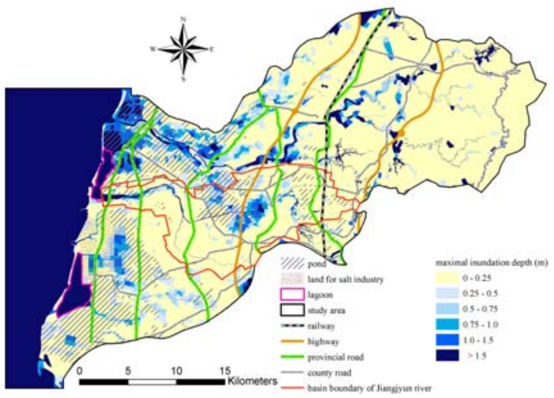
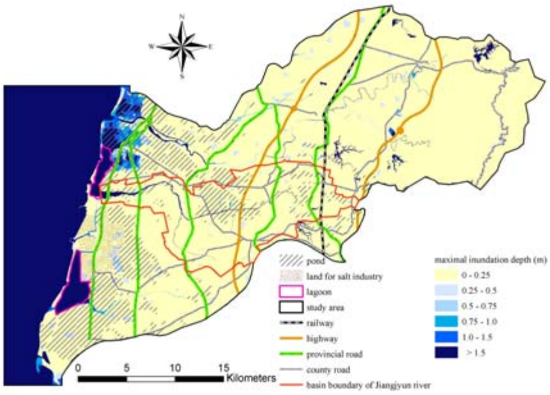


Figure 5 The simulated maximum inundated depth of Typhoon Haitang in 2005

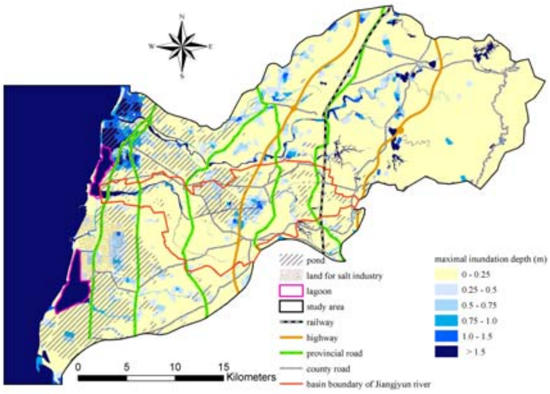
Figure 6 The inundated depth of Typhoon Haitang in Tainan county in 2005

4.3 Simulation for designed heavy-rains

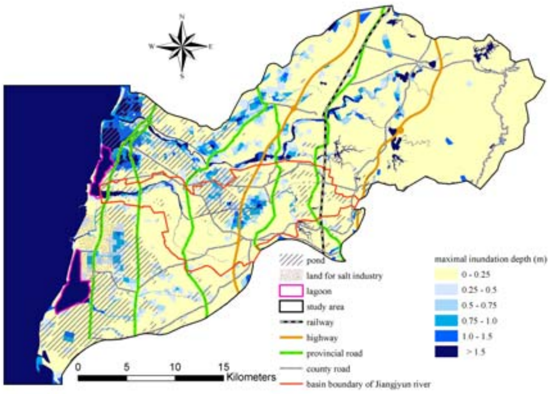
In order to investigate the influence of storm surges on the inundated potential in the coastland, the Physiographic Inundation model is applied to simulate the inundated potential of the study area with the hydrologic conditions for the duration of 2-hour, 4-hour, 12-hour, and 24-hour floods for 5- year, 10- year and 100-year return periods. The storm surge and the astronomical tide were used as tidal conditions. The results for simulating the inundated potential of the study area were illustrated in the figure of the inundated depth. The inundated potential of the study area with the hydrologic conditions for the duration of 4-hour, 12-hour, and 24-hour floods for 5- year and 100-year return periods were utilized as an illustrative example as shown in Figures 7 and 8.



4-hour duration

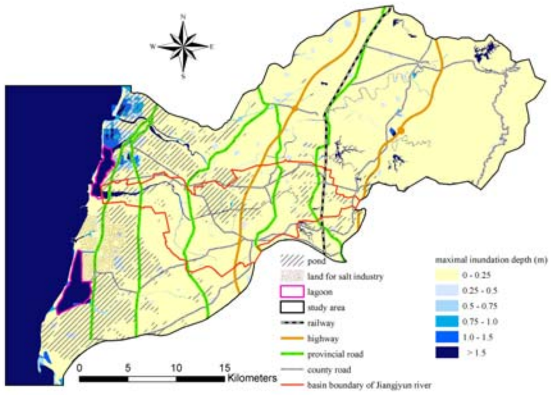


12-hour duration

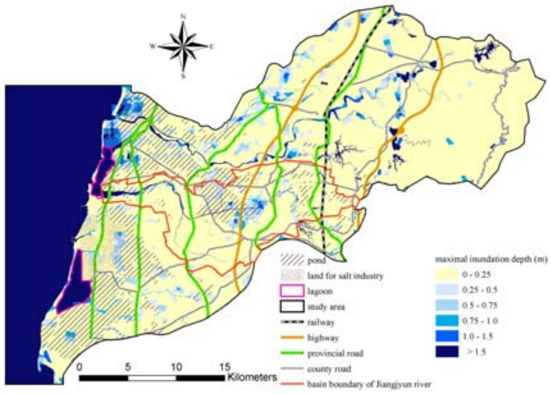


24-hour duration

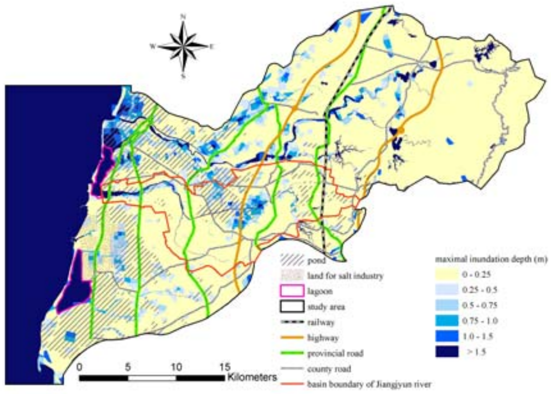
Figure 7(a) Comparison of the simulated maximum inundated depth of 5-year return period (storm surge)



4-hour duration

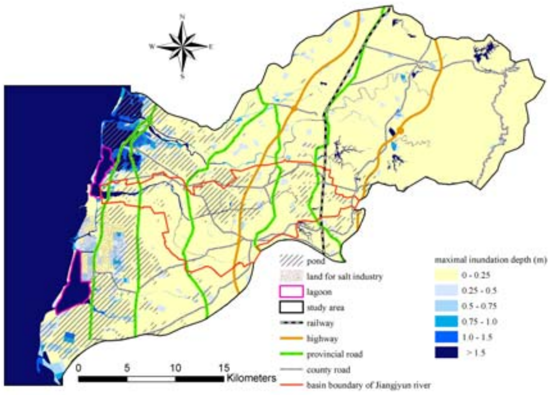


12-hour duration

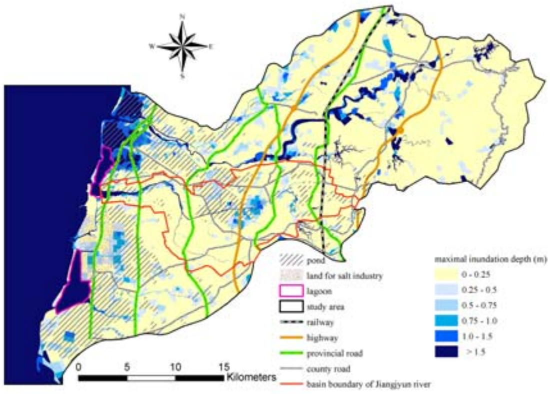


24-hour duration

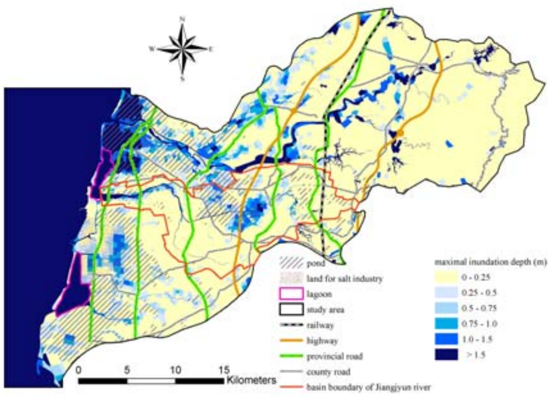
Figure 7(b) Comparison of the simulated maximum inundated depth of 5-year return period (astronomical tide)



4-hour duration

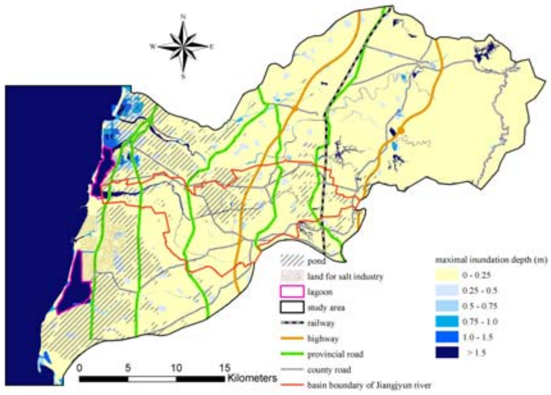


12-hour duration

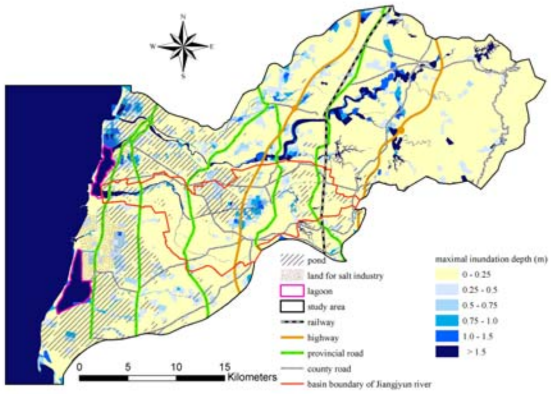


24-hour duration

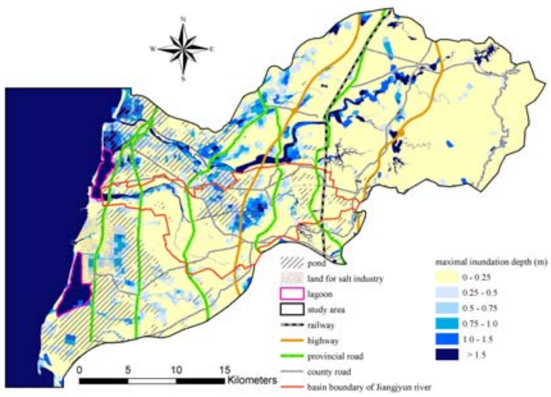
Figure 8(a) Comparison of the simulated maximum inundated depth of 100-year return period (storm surge)



4-hour duration



12-hour duration



24-hour duration

Figure 8(b) Comparison of the simulated maximum inundated depth of 100-year return period (astronomical tide)

As shown in Figures 7 and 8, the inundated area and maximum inundated depth increase significantly with rainfall duration on the condition of the same return period. The inundated area and maximum inundated depth increase significantly with return periods. Thus, the inundated area and maximum inundated depth increase significantly with return periods on the same rainfall duration. Further, in order to investigate the influence of storm surges on the inundated potential in the coastland, the inundated depths and volumes of 24-hour duration for 5- year 10-year, and 100-year return periods with storm surge or astronomical tide conditions were summed up individually. The increases in inundated depths and volumes were summarized in Table 1.

In Table 1, a negative value indicates the decrease in inundated volumes. The influence of storm surges on the inundated potential in the coastland is illustrated at Table 1. As shown at Table 1, the increases in inundated depths and volumes increase significantly when the storm surge occurs. As shown in Figures 7, 8 and, Table 1, the most difference in inundated volumes of different return periods and durations occurr in the coastland. The inundated volumes with the inundated depths of 5-year and 10-year return periods that were greater than 75 cm increase significantly when storm surge occurs. The inundated volumes with the inundated depths of 5-year and 10-year return periods that were less than 75 cm might increase. The inundated volumes with the inundated depths of 100-year return period that were greater than 25 cm increase significantly. The inundated volumes with the inundated depths of 100-year return period that were less than 25 cm might even decrease.

Table 1 Decrease in inundated volume (in 10^3 m^3) of the cases in 2-hour duration floods for 2-, 10- and 100-year return-periods with storm surge or astronomical tide condition

Return-period (years)	Inundation depth (m)						Sum
	0-0.25	0.25-0.50	0.50-0.75	0.75-1.0	1.0-1.50	>1.50	
5	-373.92	1266.40	-3152.80	2371.84	5529.59	121736.50	127377.62
10	171.60	459.26	-1504.54	339.76	7030.66	147986.50	154483.24
100	-453.68	1770.05	3049.44	357.28	8238.54	264175.00	277136.62

5. CONCLUSIONS

In the same designed heavy-rains, regardless of storm surges occur or not, there are obvious influences on the inundation depth and area in the coastland. Inundating potential reveals that inundated potential in the coastland in terms of inundation depth and area in the case of storm surges is plainly greater than that in the astronomical tide. When planning the scale of drainage systems and dikes in the coastland, proceeding typhoon and heavy-rain events and storm surges simulation of the inundating potential which caused by typhoons are necessary. In addition, it is crucial to compare and review the inundation phenomena of flood-prone areas and then to provide improvement.

ACKNOWLEDGMENTS

This study was supported fanacially by a grant from the Water Hazard Mitigation Center, Water Resources Agency, Ministry of Economic Affairs.

REFERENCES

Chen, C.N., Tsai, C.H. and Tsai, C.T. (2007), Reduction of discharge hydrograph and flood stage resulted from upstream detention ponds, *Hydrological Processes*, 21, pp. 3492–3506.

Lee, H.Y. (1999), A Study on Automated District Cells of the Watershed, *Master Thesis, Department of Hydraulics and Ocean Engineering, National Cheng-Kung University*, *Tainan, Taiwan*.
Water Hazard Mitigation Center, Water Resources Agency, Ministry of Economic Affairs (2007), A study on the surge and cross-watershed runoff for the drainage system of the coastland (1/2), *Technical Report, MOEA, Taipei, Taiwan*.
Yang , C. J. (2000), Study on Construction of a Physiographic Inundation Forecasting System, *Doctoral Thesis, Department of Hydraulics and Ocean Engineering, National Cheng-Kung University, Tainan, Taiwan*.
Yang, C. R., and Tsai, C. T. (1997), Development of the GIS-Base Flood Information System for Floodplain Modelling and Damage Calculation, *Journal of the American Water Resources Association*, 36(3), pp. 567-577.