A GIS-based Approach for Flood Vulnerability Assessment in Hoa Vang District, Danang City, Vietnam.

Tran Thi An¹, Venkatesh Raghavan², Nguyen Vinh Long³, Saizen Izuru⁴, Narumasa Tsutsumida⁴
¹University of Science and Education, The University of Danang, Vietnam;
²Graduate School for Creative Cities, Osaka City University, Japan;
³Central and Highland Sub-Department of Natural Disaster Management, Vietnam Disaster Management Authority;
⁴Graduate School of Global Environmental Studies, Kyoto University, Japan.
Email: tran@ued.udn.vn

Abstract: Danang is a coastal city in the Central Region, VietNam which is considered as a sensitive area under the high risks of natural disasters and climate change. Located in downstream of Vu Gia - Thu Bon river system, Da Nang city is often inundated in flood season. Hoa Vang district is considered as the most flood damaged region in Danang City due to its location and topography. Assessing socio-economic vulnerability of floods is important in the management of natural disaster risks, from that developing solutions to mitigate the damage caused by floods. This study develops a flood vulnerability assessment method for the Hoa Vang district, Danang City based on the Geographic Information System (GIS). Through analyzing the inundation situation and local socio-economic conditions, the research has selected and developed a set of criteria to assess the flood vulnerability for the study area and presented in GIS environment. Based on the spatial analysis methods in GIS, the study has identified Flood Vulnerability Index (FVI) and generated the flood vulnerability map for Hoa Vang district, Danang city. The results from this study are important in order to propose the solutions for responding to flood hazard in Da Nang City.

1. Introduction

Flooding is one of the most frequent and damage-causing natural disasters in Vietnam. Flooding results from the typical tropical monsoon climatic features exacerbated by topographic characteristics and recent climate change (Central Committee for Flood and Storm Control, 2006). The areas in Central Vietnam, especially Danang and Quang Nam provinces have experienced several severe floods in the past. Located in downstream of Vu Gia - Thu Bon river system, Da Nang City is often inundated in flood season. Hoa Vang district is considered as the most flood damaged region in Danang City due to its location and topography. Assessing socio-economic vulnerability of floods is important in management of natural disaster risks and developing the strategies to mitigate the damage caused by floods. This study develops a flood vulnerability assessment method for the Hoa Vang district, Danang City based on the Geographic Information System (GIS). Due to the frequency of the flood events, vulnerability assessment becomes indispensable for evaluation the flood risk in this region. Several methods for flood vulnerability assessment have been developed using various hydrological, meteorological and geomorphological approaches (e.g., Kenny, 1990, Ballais et al., 2005, Mafreda et al., 2011 and Forkuo, 2011). Some authors also tried to characterize the flood potential in Danang area, based on geo-morphological studies integrated with remotely sensed data (Ho et al., 2012 and Do and Nagasawa, 2014). However, those studies mostly focus on evaluation the flood hazard exposure which is one of the components of the flood vulnerability. This could lead to inaccurate in obtained results when developing a comprehensive flood mitigation plan.

This study aims to evaluate the flood vulnerability for a rural district in Danang City. The concept of vulnerability has been more widely studied from various perspectives. In this study, the flood vulnerability is evaluated using the approach proposed by the IPCC (Intergovernmental Panel on Climate Change) in which vulnerability is understood as a function of exposure, sensitivity, and adaptive capacities. “Exposure,” as the first component of vulnerability, is considered as the flood hazard potential of the study area. “Sensitivity” is defined as the resilience of the system experiencing such hazards. In the IPCC’s fourth assessment report (2007), sensitivity is defined with reference to climate change as “the degree to which a system is affected, either adversely or beneficially. “Adaptive capacities” are considered as the social and technical skills and strategies that are directed towards responding to climate changes.
This study tends to identify the flood vulnerable areas at commune level according to different susceptibility degree under the impacts of natural and socio-economic condition. Therefore, the method of using satellite image data (remote sensing) and Geographic Information System (GIS) combining field survey data is main approach in this research. Integrating remote sensing and GIS methods to assess the impact of natural disasters (floods, droughts, salinization, etc.) is considered as an effective method with advantages of quick and accurate updating according to temporal and spatial changes of natural disasters. In fact, remote sensing and GIS methods have been widely applied in many studies in the world related to climate change (Ouma and Tateishi, 2014, Feyissa et al., 2018, K.A. Nguyen et al., 2016).

In order to quantitatively assess the impact of flood, the vulnerability index is calculated based on the parameter set for each component of the vulnerability function. The parameters are standardized from 0 - 1 and integrating with the AHP hierarchical analysis method (Saaty, 2008) to determine the weights for component variables, thereby determining the vulnerability index for each area. The results of the project will identify communes with different levels of vulnerability to flood from low, medium to high. This study is a baseline for proposing a number of adaptive solutions for areas under highly flood vulnerability.

![Figure 1. Research Approach for Flood Vulnerability Assessment (IPCC, 2014).](image)

2. Methodology

2.1. Study Area and Data Used

The study area comprises of 746.6 square kilometers of Hoa Vang district located in the southern and western of Danang city. Figure 1 shows the location of study area in Vietnam. The area is crossed by Cam Le river and Cu De river which are two main river system in Danang City. This area is characterized by two seasons in a year: a rainy season from August to December and a dry season from January to July, with rainfall mainly concentrated from September to December. On an average, this area is directly or indirectly affected by 1-2 typhoons and 1-2 serious flooding spells each year (Do and Nagasawa, 2014).

The topographic characteristic of Hoa Vang district is varied with elevation ranging from 0m to 1663m above mean sea level and spreading from mountain in the west to flat region in the east. The varying topography is one of reason causes the different exposure to flood hazard. Since the topography is one of the main causative factor to flood exposure, this study took the advantages of various elevation data sources including the global DEMs (ALOS DEM, ASTER GDEM and SRTM) and the spot height elevation data of Danang City. In addition to elevation data, the statistical data on socio-economic condition of Hoa Vang district is also important for evaluation the flood risk vulnerability. These data were generated from the Statistical Yearbook of Hoa Vang district in 2018. In order to evaluate the accuracy of the flood vulnerability assessment, the field survey data on flood sign was generated from a survey conducted on July 2020 with the information about the location and depth of the flood pillar points was also used in this study.
2.2. Data Processing

Various data called conditioning factors are needed as independent variables in the process of vulnerability mapping. Exposure is defined by the extent to which people, property, and infrastructure are exposed to a hazard event. Vulnerability is specified by the extent to which people are susceptible to, or unable to cope with, the impacts. This study applied the method of IPCC (2014) to measure the flood vulnerability as equation below:

$$FVI = E + S - AC$$  \hspace{1cm} (1)

Where $FVI$ is the flood vulnerability index, $E$, $S$ and $AC$ is respectively stand for exposure, sensitivity and adaptive capacity which are the three main components of $FVI$.

Based on the evaluation of natural conditions of study area and review of previous research related to flood vulnerability, we have selected totally nine indices for flood vulnerability assessment in Hoa Vang district. The exposure component includes four main criteria in which elevation, flow accumulation and Topographic Wetness Index (TWI) are the main causative factors that proved in previous study (Kenny, 1990, Ballais et al., 2005, Mafreda et al., 2011, Tran et al., 2017). In addition, the distance from the river channel (DIST) plays an important role in flood hazard since floods are mostly caused by water overflows from rivers. Due to its important role, DIST has been assigned as one of criteria for exposure. Areas near the river channels are at high exposure of flood hazard (Tran Thi An et al., 2017). The distance from the river channel in this study was calculated using the Euclidean distance method that was integrated in GRASS GIS software (r.grow.distance). Considering the sensitivity, land-use and population are widely known as main relative factors to flood hazard. The population index is calculated by number of people in an area unit (population density) and normalized in a standard scale. Regarding the land-use factor, we have selected two land-use types including percentage of paddy and percentage of built-up which have closed relationship to flood that have observed in the study area. The adaptive capacity is usually related to social condition and strategies responding to climate change. In this study, two main factors including average income and poverty index which are directly related to social condition have been chosen for generation of adaptive capacity for Hoa Vang district. The study approach and the parameter scheme for flood vulnerability assessment in Hoa Vang district is shown in Figure 3.

The collected data including both elevation and statistical data was processed and transformed into GIS format. Subsequently, the GIS data including both spatial and attribute information was normalized into scale from 0 to 1. The normalization process is follow the method of UNDP, 2006 as described below:
The equation 2 is used when the parameter is in direct proportion to flood vulnerability and the equation 3 is used in the opposite case. The flood vulnerability index was generated by combining all of criteria integrating with their weights. Figure 4 is the representation of each causative parameter in flood hazard vulnerability for the study area.

\[
x_{ij} = \frac{X_{ij} - \text{Min}[X_{ij}]}{\text{Max}[X_{ij}] - \text{Min}[X_{ij}]} \quad (2)
\]

\[
x_{ij} = \frac{\text{Max}[X_{ij}] - X_{ij}}{\text{Max}[X_{ij}] - \text{Min}[X_{ij}]} \quad (3)
\]

The equation 2 is used when the parameter is in direct proportion to flood vulnerability and the equation 3 is used in the opposite case. The flood vulnerability index was generated by combining all of criteria integrating with their weights. Figure 4 is the representation of each causative parameter in flood hazard vulnerability for the study area.

Figure 3. Flowchart of data processing for flood vulnerability assessment

a. Flow accumulation

b. Distance to river channel (m)
2.3. Generation of Elevation Data

Topography is the first-order control on spatial variation of hydrological conditions (Sorensen et al., 2006). Digital Elevation Model (DEM) represents one of the main causative factors of flooding where lower elevations assume a higher flood hazard potential. In this study, the DEM data used for evaluation of flood vulnerability is generated using the method proposed in the previous study of the first author (Bien et al., 2018) which combined the three main global DEM sources (ALOS DEM, ASTER GDEM and SRTM) and the spot height elevation data of Danang City.

In almost studies, the free access global DEMs such as GDEM, SRTM and ALOS-30 DEM are used frequently. However, global DEMs with its inherent limitations sometimes affect the quality of application results (Tran et al., 2014). This study proposes a method for improving quality of global DEMs and estimating a combined elevation surface using Geographically Weighted Regression (GWR). The GWR approach for spatial modeling was becoming an important tool which provides technique to deal with spatial non-stationarity in multivariate regression and estimates regression coefficients locally using spatially dependent weights (Brunsdon et al., 1996). GWR has been applied more widely in urban geographical, economic and environmental studies.

This study has explored the advantages of GWR for estimation of a new DEM using three global DEMs (ALOS AW3D30, ASTER GDEM, SRTM) and referenced elevation points. The global DEMs have been used as multiple independent variables (explanatory variables) and reference points are dependent variable in the GWR model. In GWR model, the terms of bandwidth and kernel function have effect on the estimation result. Various conditions of bandwidth and kernel were applied and bi-square function (equation...
2) with fixed bandwidth size 50 showed the best estimated DEM.

\[ w_p = (1 - (d/bw)^2)^2 \]  

(4)

Where, \( bw \) is the bandwidth, \( d \) is the distance from a pixel to the current pixel, and \( w_p \) is the weight assigned to a pixel. GWR is available as module \( r.gwr \) in GRASS GIS. As a result, the estimated DEM which derived from three global DEMs and the number of 50,000 reference elevation points was generated (Figure 5).

![GWR model](image)

Figure 5. GWR model used in DEM estimation (Bien et al., 2018).

As the results, DEM generated using GWR model for the study area (Figure 2) has the elevation range from 0m to 1663m with the RMSE of 4.1m and the correlation coefficient \( R^2 \) between the GWR DEM and reference data also shows the significant correlation, with \( R^2 = 0.9994 \). It is clear that the GWR has better accuracy than any global elevation source for the study area. This GWR DEM data is used for generation of topographic feature related to flood susceptibility such as flow accumulation and topographic wetness index. These parameters are considered as causative factor of flood hazard exposure which is the main component in flood vulnerability.

2.4. Determination of the Weights for Parameters

The flood vulnerability is determined by integrating all of the criteria along with their corresponding weights. This study used the Analytic Hierarchy Process (AHP) which is a method developed by Saaty (2008) to calculate the weight for the causative parameters to flood vulnerability. AHP is considered as an effective tool for dealing with complex decision making. Weighting by AHP is widely used in many studies (Mishra, 2013, Ouma and Tateishi, 2014, Kazakis et al., 2015 and Danumah et al., 2016). The process of AHP can be summarized in four steps (Ouma and Tateishi, 2014). The first step includes dividing the problem into a number of simpler problems (elements) in the form of a decision hierarchy. The second step is determining priorities among the decision elements of the hierarchy. This step evaluates the priorities of criteria in relation to the global goal and assigns the values subjecting to the judgments in a form of pair-wise comparison matrix. The assignment of the relative significant between criteria is presented in Saaty (2008) with values from 1 to 9 indicating less important to much more important, respectively. In the third step, the relative weights \( w \) of the decision elements are calculated. Detail of applying AHP method in flood hazard assessment is presented in Tran et al., 2017. This study developed the criteria system for flood vulnerability assessment and the results of weight calculation for each element are shown in Table 1. The last step is checking the consistency of the subjective evaluations. In order to evaluate the consistency of the pair-wise
comparison in AHP, the Consistency Index (CI) is determined based on maximum Eigenvalue ($\lambda_{\text{max}}$). $\lambda_{\text{max}}$ is calculated based on the method proposed by Vargas, 2010. The Consistency Index (CI) is determined by the equation below:

$$ CI = \frac{\lambda_{\text{max}} - n}{n-1} $$  \hspace{1cm} (5)

Where $\lambda_{\text{max}}$ is the maximum Eigenvalue of the comparison matrix (Vargas, 2010) and $n$ is the number of evaluated criteria. In order to verify whether the CI is adequate, Saaty (2008) suggests the Consistency ratio (CR) which is determined as the ratio between the CI and the random consistency index (RI). The calculation of CR is given by the following equation:

$$ CR = \frac{CI}{RI} $$ \hspace{1cm} (6)

Where CR is the consistency ratio, CI is the consistency index, and RI is the random consistency index. Values of RI are dependent of the number of criteria (n) which are specified in Danumah et al., (2016). The comparison matrix is consistent if the resulting CR is less than 0.1 or 10% (Saaty, 2008). When CR exceeds 0.1, it is necessary to revise the comparison matrix and re-calculate the weights for better weighting scheme.

3. Results and Discussion

In this study, the weight was calculated separately for every component of flood vulnerability including exposure, sensitivity and adaptive capacity. The results of weight calculation are shown in Table 1. The CR for the weighting scheme in the exposure component is 0.42 and in the case of sensitivity is 0.002 accordingly. Since the CR values are less than 0.1, it is clear that the comparison matrixes in the AHP method are consistent and the weighting schemes are reasonable. In the determination of weight for parameter in the adaptive capacity component, since we have only two criteria which average income and poverty index and the contribution of these parameters are equally, hence the equal weights were applied as shown in Table 1. Finally, the flood vulnerability index is calculated using the equation (1) in which the weight of each component is considered as equally.

Flood vulnerability index is calculated by combining of the exposure, sensitivity and adaptive capacity using the equation 1. Subsequently, flood vulnerability values were divided into different ranges from 0 to 1 corresponding to the vulnerability from low, medium, high to very high. The division scheme is using equal range as below: 0 – 0.25 (low); 0.25 – 0.5 (medium); 0.5 – 0.75 (high) and 0.75 – 1.0 (very high). As the result, the very high vulnerability areas in Hoa Vang district belong to the lowland communes including Hoa Tien, Hoa Chau and Hoa Phuoc. These areas are characterized by the low topographic, nearest distance to river channel and very high density of population. Comparing to field survey data on flood sign, it is shown that most of flood pillar point in this study area located in the high vulnerable communes. The high correspondence with field flood pillars reveals the effectiveness of multi-parametric approach in flood hazard assessment. On the other aspect, the low vulnerability level is corresponded to Hoa Bac commune which has high elevation and very sparse population density. It can be concluded that the evaluation of flood vulnerability in this study is reliable and can be useful for flood mitigation plan in Hoa Vang district.

| Table 1. Criteria and corresponding weights for evaluation flood vulnerability in Hoa Vang district |
|-----------------|-----------------|-----------------|-----------------|
| Components      | Criteria        | Method of generation | Data Source            | Weight |
| Exposure        | Elevation       | GWR               | Global DEMs and Spot height data | 0.46  |
|                 | Flow accumulation| Hydrologic analysis | GWR DEM               | 0.1   |
|                 | TWI             | Hydrologic analysis | GWR DEM               | 0.16  |
|                 | Distance to river| Euclidean distance | River channel          | 0.28  |
| channel | Sensitivity | Population | Statistic | Statistical Yearbook | 0.16 |
|---------|-------------|------------|-----------|----------------------|------|
|         | Percentage of Paddy | Statistic | Statistical Yearbook | 0.29 |
|         | Percentage of Built-up | Statistic | Statistical Yearbook | 0.54 |
| Adaptive Capacity | Average Income | Statistic | Field Survey | 0.5 |
|         | Poverty Index | Statistic | Statistical Yearbook | 0.5 |

4. Conclusion
The present study demonstrates the effectiveness of integrating GIS method and multi-parametric AHP model for flood vulnerability assessment in a rural district of Danang City. This study has generated the GIS database for flood hazard assessment in which the high quality elevation data has been developed and applied effectively in generation of parameters for evaluation of flood vulnerability. This study has first time applied the approach of IPCC (2014) in flood vulnerability assessment for Hoa Vang district at commune level. AHP method was applied to determine the weights for each parameter and compute the flood vulnerability index (FVI) including three main components which are exposure, sensitivity and adaptive capacity. Flood vulnerability map has been generated based on categorizing of FVI into four levels including low, medium, high and very high. Results of flood vulnerability assessment in this study revealed good agreement between high vulnerability areas and flood pillar points which is field survey data. The proposed method shows the potential of applying AHP method in flood vulnerability model based on IPCC approach in larger extent of study area.

![Figure 6. Flood Vulnerability Map for Hoa Vang District – Danang City](image)
Acknowledgement

This work was supported by the Graduate School of Global Environmental Studies (GSGES) Grand Seed 2020, Kyoto University, Japan and the University of Danang, Vietnam. The authors would like to express sincere thanks to the GSGES and the University of Danang for providing research facilities and financial support for this study. The authors also would like to thank members at Faculty of Geography, University of Education, The University of Danang for their help with field data verification.

References

[1] Ballais J. L., Garry G. and Masson M., 2005, Contribution of Hydrogeomorphological Method to Flood Hazard Assessment: the Case of French Mediterranean Region. Comptes Rendus Geoscience, 337 (13), pp 1120-1130.
[2] Beven, K. J. and Kirkby, M. J., 1979, A Physically Based Variable Contributing Area Model of Basin Hydrology. Hydrological Sciences-Bulletin-des Science Hydrologiques, 24(1), pp 43-69.
[3] Bien L.V., Venkatesh Raghavan, Vinayaraj Poliyapram, Tran Thi An (2018) Geographically Weighted Regression for Surface Elevation Estimation Using Global DEMs and Spot Height Data, GIS-IDEAS 2018, Cantho, Vietnam, JVGC Technical document No.9, pp 233-238.
[4] Danumah, J. H., Odai, S. N., Saley B. M., Szarzynski, J., Thiel, M., Kwaku, A., Kouame, F. K. and Akpa, L. Y., 2016, Flood Risk Assessment and Mapping in Abidjan District using Multi-Criteria Analysis (AHP) Model and Geoinformation Techniques, (cote d’ivoire). Geoenvironmental Disasters, 3(10), pp 1-13.
[5] Do, T. V. H. and Nagasawa, R., 2014, Potential Flood Hazard Assessment by Integration of ALOS PALSAR and ASTER GDEM: a Case Study for the Hoa Chau commune, Hoa Vang District, in Central Vietnam. Journal of Applied Remote Sensing, 8, pp 1-12.
[6] Forkuo, E. K., 2011, Flood Hazard Mapping using ASTER Image Data with GIS. International Journal of Geomatics and Geosciences, 1(4), pp 933-950.
[7] Feyissal G., Gete Zeleke, Ephrem Gebremariam and Woldeamlak Bewket (2018) GIS based quantification and mapping of climate change vulnerability hotspots in Addis Ababa, GeoEnvironmental Disasters (2018) pp 5-14, doi.org/10.1186/s40677-018-0106-4.
[8] Ho, T. K. L, Yamaguchi, Y. and Umitsu, M., 2012, Rule-Based Landform Classification by Combining Multi-spectral/temporal Satellite Data and the SRTM DEM. International Journal of Geoinformatics, 8, pp 27-38.
[9] IPCC (2007) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate. Geneva.
[10] IPCC (2014). Climate Change 2014: the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate. Geneva.
[11] Kazakis, N., Kougias, I. and Patsialis, T., 2015, Assessment of Flood Hazard Areas at a Regional Scale using an Index-Based Approach and Analytical Hierarchy Process: Application in Rhodope-Evros Region, Greece. Science of the Total Environment, 538, pp 555-563.
[12] Kenny, R., 1990, Hydrogeomorphic Flood Hazard Evaluation for Semi-arid Environments, Quarterly Journal of Engineering Geology, 23, pp 333-336.
[13] Liu, Y. and De Smedt, F., 2005, Flood Modeling for Complex Terrain using GIS and Remote Sensed Information. Water Resources Management, 19, pp 605-624.
[14] Manfreda, S., Di Leo, M. and Sole, A., 2011, Detection of Flood-Prone Areas using Digital Elevation Models. Journal of Hydrologic Engineering, 16, pp 781-790.
[15] Mishra, K., 2013, Geomorphic Studies and Flood Risk Assessment of Kosi River Basin using Remote Sensing and GIS Techniques. Master thesis, Indian Institute of Technology. M.Tech 2011-2013.
[16] K. A. Nguyen, Yuei An Liou, Ming Hsu Li (2016) Zoning eco-environmental vulnerability for environmental management and protection. Ecological Indicators, 69, 100 – 117.
[17] Ouma, Y. O. and Tateishi K. A. Nguyen, Yuei An Liou, Ming Hsu Li (2016) Zoning eco-environmental vulnerability for environmental management and protection. Ecological Indicators, 69, 100 – 117.
[18] Saaty, T. L., 2008, Decision Making with the Analytic Hierarchy Process, International Journal of Services Sciences, 1 (1), pp 83-98.
[19] Tehrany, M. S., Lee M. J., Pradhan, B., Jebur, M. N. and Lee, S., 2014, Flood Susceptibility Mapping using Integrated Bivariate and Multivariate Statistical Models. Environment Earth Sciences, 72(10), pp 4001-4015.
[20] Tehrany, M. S., Pradhan, B. and Jebur, M. N., 2015, Flood Susceptibility Analysis and Its Verification using Novel Ensemble Support Vector Machine and Frequency Ratio Method, Stochastic Environmental Research and Risk Assessment, 29 (4), pp 1149-1165.
[21] Tran, T. A., Raghavan, V., Masumoto, S., Vinayaraj P. and Yonezawa, G., 2014, A Geomorphology-Based Approach for Digital Elevation Model Fusion - Case Study in Danang City, Vietnam, Earth Surface Dynamics, 2, pp 403-417.
[22] Tran, T.A., Raghavan, V., Masumoto, S., and Yonezawa, G. (2017), Application of Multi-parametric AHP for Flood Hazard Zonation in Coastal Lowland Area of Central Vietnam. International Journal of Geoinformatics, 13 (1), pp. 23-34.
[23] Vargas, R., 2010, Using the Analytic Hierarchy Process (AHP) to Select and Prioritize Projects in a Portfolio, PMI Global Congress 2010, North America, Washington - DC - EUA.