Application of Multi-parametric AHP for Flood Hazard Zonation in Coastal Lowland Area of Central Vietnam

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Abstract

Flooding is one of the most commonly occurring natural hazards worldwide. Multiple geomorphic factors such as elevation, slope, topographic wetness index and distance from the river channel impact on flood susceptibility. Determining the effect of each factor and integration of their influence on flood hazard zonation has become an essential need in flood management. This study attempts to develop a hierarchical model for flood hazard zonation in the coastal lowland of Central Vietnam by using a multi-parametric approach. Five factors including elevation based flood inundation, distance from the river channel, land use, slope and topographic wetness index have been taken into consideration for developing flood hazard zonation. The Analytical Hierarchy Process (AHP) method was applied to assign weights according to the pair-wise comparisons of the parameters. These weights were used for calculation of Flood Hazard Index which was then evaluated and classified into four zones of flood hazard susceptibility. The result of flood hazard zonation was compared with field survey flood pillar points and flood inundation map extracted from ALOS PALSAR image in 2007 for validation. The comparison with field flood pillars indicated good correspondence with demarcated zones and estimated depth. Further, nearly 80 percent of inundated areas observed in ALOS PALSAR data fall in the high and very high flood hazard zones. The excellent agreement between flood hazard zonation map and observed inundation demonstrate the effectiveness AHP based method in flood hazard assessment.

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 coastal lowland area in Central Vietnam is characterized by high rainfall, narrow coastal plain, short steep rivers which are potential for flood occurrence. The average annual rainfall in upland areas of the river basins in this region is approximately 3000-4000mm which is highest for the country. More than seventy percent of the annual rainfall is received during the rainy season lasting from September to December and results from storms and typhoons that cause flooding (Ho et al., 2012). The areas in Central Vietnam, especially Danang and Quang Nam provinces have experienced several severe floods in the past. Due to the frequency of the flood events, hazard zonation becomes indespensible for evaluation the flood risk in this region. Several methods for flood hazard mapping 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 hydro-geomorphological methods integrated with remotely sensed data (Ho et al., 2012 and Do and Nagasawa, 2014). However, those studies reveal limitations due to lack of high-resolution digital elevation model (DEM) and satellite data acquired during flood events. This could lead to inaccuracy in obtained results when developing a comprehensive flood mitigation plan.

This study aims to generate the flood hazard potential for coastal lowland south of Danang City, Vietnam using multi-parametric Analytical Hierarchy Process (AHP). A 5m Digital Elevation Model (DEM) was generated using BS-Horizon method (Nonogaki et al., 2012) and used for extraction of geomorphologic parameters such as, Elevation-based Flood Inundation (EFI), slope, Topographic Wetness Index (TWI).

These parameters along with the land use and distance from the river channel (DIST) were used in AHP model for pair-wise comparisons and to determine respective weights for calculating Flood Hazard Index (FHI). Flood hazard zonation proposed in the present study shows good correlation to flood pillar data and flood inundated areas derived from ALOS PALSAR image.

2. Study Area and Data Used

The study area comprises of 98 square kilometers of lowland area located in the south of Danang city. Figure 1 shows the location of study area in Vietnam. The study area includes the rural area in the southern part of Danang city and a northern part of Dien Ban district of Quang Nam province. The area is covered by Cam Le river and Yen river in the north and west. Yen river flows to Cam Le river and merges with Cai and Vinh Dien rivers, located in the center of the study area (Figure 1). Both Cai and Cam Le flow into Han river that is a part of Vu Gia river system. The east side of the study area is covered by Co Co river that used to be a tributary of Thu Bon river, the biggest river in Central Vietnam. Co Co river has been disconnected from Thu Bon river now due to the filling of the channel. The topography is relatively flat with an elevation range from 0 to 10m. 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 *in-situ* spot height data surveyed by Department of Natural Resource and Environment (DONRE), Danang city in 2009 includes 79,600 elevation points that were used for generation of 5m DEM for the study area. Landsat TM satellite imagery in 2007 was used for extraction of land use that relates to flood hazard zonation. Further, RapidEye imagery of 5m resolution was also used for detection of river channels. Flood pillar data collected during field survey carried out during March 2015 was used as reference data to evaluate the flood hazard zonation map. In addition, flood inundation areas extracted from ALOS PALSAR in 2007 was also used for validation of the flood hazard zones demarcated from this study. The data used is described in Table 1.

3. Methodology

The flood hazard zonation for the study area was prepared using multi-parametric approach. Five causative factors of the flood including EFI, DIST, Landuse (LU), Slope (S) and TWI were taken into account in AHP method for evaluation of flood hazard potential of the study area. AHP determines the relative importance of causative factors by a paired comparison matrix and determines the weight for each parameter. Accordingly, an index called Flood Hazard Index (FHI) has been devised for the purpose of hazard zonation based on the reference from method of Kazakis et al., (2015).

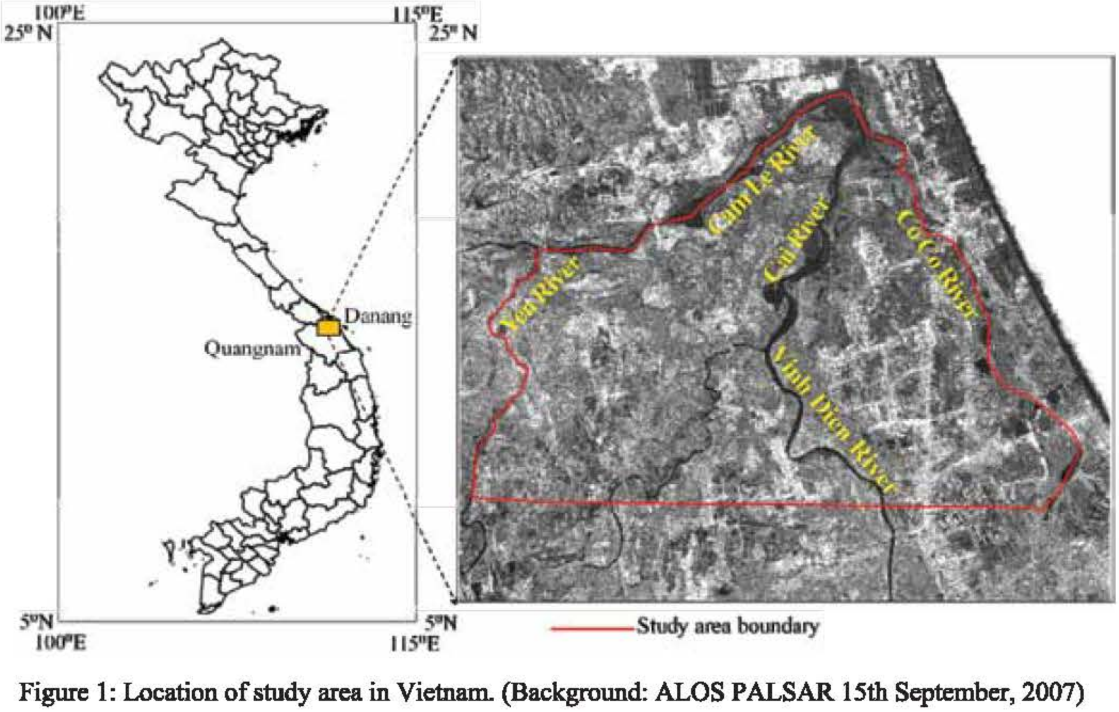


Figure 1: Location of study area in Vietnam. (Background: ALOS PALSAR 15th September, 2007)

Table 1: Data used in this study

Data	Type of data	Date	Resolution
DEM	Point elevation	December 2009	5.0 m (Interpolated)
Satellite data	ALOS PALSAR	2007/10/31	12.5 m
	Landsat TM	2007/03/16	30m
	RapidEye	2014/03/02	5m
Field survey data	Flood pillar points	March 2015	NA

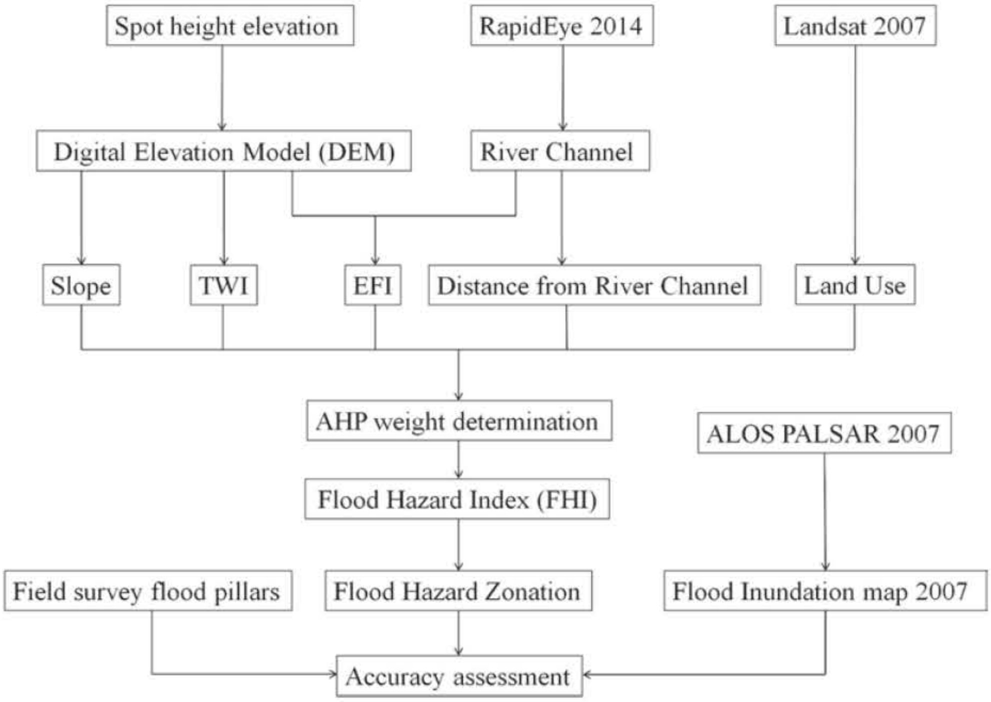


Figure 2: Flow chart of the flood hazard zonation

FHI aims to classify areas depending on susceptibility to flooding based on the quantitative determination of the weight for each parameter. The flow chart in Figure 2 describes the method of flood hazard zonation proposed in this study. Following the calculation of the weights, the FHI can be calculated using the Equation 1:

$$FHI = \sum_{i=1}^{n} r_i \times w_i = (r_{EFI} \times w_{EFI}) + (r_{DIST} \times w_{DIST}) + (r_{LU} \times w_{LU}) + (r_S \times w_S) + (r_{TWI} \times w_{TWI})$$

Equation 1

Where ***n*** is number of criteria, ***r*** is the rating values of parameters assigned based on their relations to flood, ***w*** is the weight of each parameter.

3.1 Data Preparation

3.1.1 DEM generation

Parameters involved in AHP model for the present study such as EFI, slope, TWI are derived from Digital Elevation Model (DEM). DEM is one of the most important input data for characterizing the geomorphological as well as hydrological conditions of the target study area. Generation of high quality DEM is essential for obtaining the accurate flood hazard zonation results. The ***in-situ*** spot height data that includes 79,600 elevation points was taken into account in BS-Horizon DEM generation (Nonogaki et al., 2012). BS-Horizon is an interpolation method based on bi-cubic spline algorithm and exterior penalty function that is implemented in a FORTRAN program. This method enables using elevation data as equality-inequality constraints on the surface (Nonogaki et al., 2012). The output DEM tends to satisfy the elevation constraints while relatively smoothing the topographic surface. The evaluation of parameters for BS-Horizon surface generation has been investigated by Tran et al., (2016). In this study, DEM surface is used for development of the flood hazard zonation map in which the potential areas assumed to be homogeneous. Therefore, this study considers the smoothness of generated surface as more important in the selection of parameter settings for DEM generation. Based on the evaluation and discussion about parameters for BS-Horizon DEM surface generation by Tran et al., 2016, and the requirement of DEM surface for the purpose of flood hazard zonation, this study has used the parameters $\alpha = 1.0\times10^3$, $M_x = 627$, $M_y = 435$, $m_1 = 0.5$ and $m_2 = 0.5$ for BS-Horizon DEM generation. Details of these parameters are described in details by Nonogaki et al., (2012) and Tran et al., (2016). As a result, the 5m resolution DEM was generated for the particular study area with an elevation range from 0m to 11.3m. The mean error of the generated DEM surface calculated in BS-Horizon program is 0.89m, however the Root Mean Square Error compared to field survey point elevation is only 0.49m. Comparing to global free DEM available in the study area (GDEM and SRTM), BS-Horizon DEM has the better RMSE compared to GDEM and SRTM reported in our earlier study (Tran et al., 2014). Therefore, the use of BS-Horizon DEM can lead to better flood hazard zonation.

3.1.2 Flood inundation map from satellite image

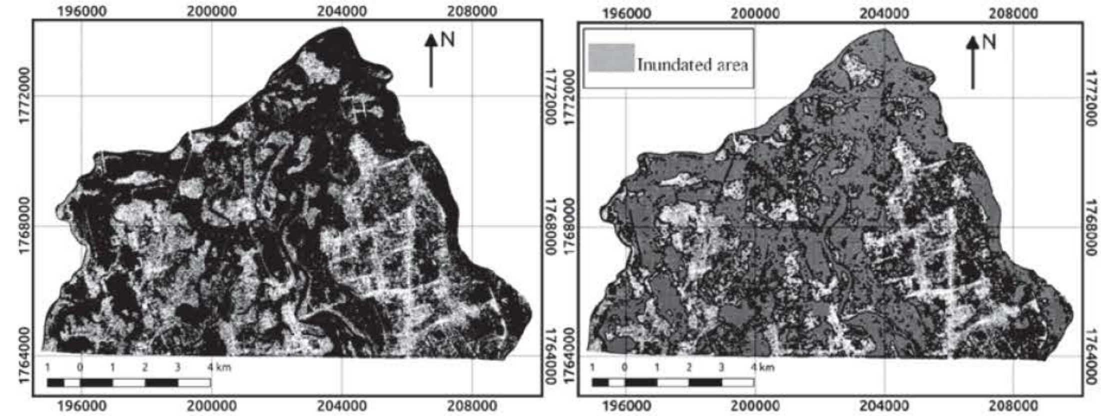
Flood inundation map is an important source for evaluation and validation of flood hazard zonation results. In this study, inundation mapping was carried using Advanced Land Observing Satellite (ALOS) Phased Array L-band Synthetic Aperture Radar (PALSAR). ALOS PALSAR imagery acquired on 31st October 2007 was used for the analysis. The PALSAR image that depicts the initial phase of a major flood event that lasted from 28th October to 9th November, 2007. ALOS PALSAR data is recorded in dual polarization, namely, HH and HV with a spatial resolution of 12.5m. In flood inundation mapping, HH polarization is reported to be more effective (Twele and Martinis, 2009), therefore HH band data was selected for extraction of flood extent. The approach adopted for mapping flood inundated areas is based on the identification of water and non-water objects. Firstly, Lee filter was applied to reduce the speckle noises on PALSAR data. Subsequently, normalized backscattering coefficient (σ^0), expressed in decibels (dB), was calculated from Digital Number (DN) value of PALSAR (Shimada et al., 2006). Backscatter coefficient obtained from ALOS PALSAR indicates the strength of microwave irradiation emitted from the antenna and returned after scattering on the surface. Analysis of the backscattering coefficient obtained from the PALSAR image enables the estimation of the area of water contained on the surface (Do and Nagasawa, 2014). The calculation of backscattering coefficient for PALSAR standard product is according to Shimada et al., (2006) using Equation 2 shown below:

$$\sigma^0 = 10*\log_{10}(DN^2) + CF$$

Equation 2

Where σ^0 is the Normalized Backscattering Coefficient (NBC), *DN* is the Radar amplitude expressed as a digital number and CF is the calibration coefficient for PALSAR standard products, and equals –83 dB (Shimada et al., 2006). In the present study, NBC was computed using PALSAR level 4.1 product.

The backscatter coefficient is reflected in response to the differences in brightness, where a water surface appears dark because the backscatter is weak on the smooth surface of the water (Do and Nagasawa, 2014). Observing from PALSAR imagery, a large area of water coverage appears as a darker color on October 31st, 2007. Based on the histogram of training samples and comparison with dark areas appearing as water on PALSAR data, a threshold of 10dB was used to separate water and non-water objects. However, the results show a number of discrete water pixels on the non-flooded areas. In this case, 5m DEM was integrated to enhance the accuracy of flood inundation map. Observing that all of the flood pillar points that record the inundation depth are located at elevation lower than 5m, a threshold of 5m was used to remove all the inundated pixels with elevation higher than 5m. Comparison with the PALSAR image on 31st October, 2007 the flood inundation map show good match with water objects derived from SAR data (Figure 3).



(a) (b)

Figure 3: ALOS PALSAR on 31st October 2007 (a) and the flood inundation map extracted from PALSAR data (b)

Table 2: Pair-wise comparison (PC), normalized values (NV) and corresponding weights for flood hazard parameters

Parameter	EFI		DIST		TWI		LU		Slope		Weight (w_i)
	PC	NV	PC	NV	PC	NV	PC	NV	PC	NV	
EFI	1	0.44	2	0.49	3	0.44	4	0.38	5	0.33	**0.42**
DIST	1/2	0.22	1	0.25	2	0.29	3	0.29	4	0.27	**0.26**
TWI	1/3	0.14	1/2	0.12	1	0.15	2	0.19	3	0.20	**0.16**
LU	1/4	0.11	1/3	0.08	1/2	0.07	1	0.09	2	0.13	**0.10**
Slope	1/5	0.09	1/4	0.06	1/3	0.05	1/2	0.05	1	0.07	**0.06**
Sum	**2.28**	**1.00**	**4.08**	**1.00**	**6.83**	**1.00**	**10.50**	**1.00**	**15.00**	**1.00**	**1.00**
λ_{max}	(0.42×2.28) + (0.26×4.08) + (0.16×6.83) + (0.10×10.50) + (0.06×15.00) = 5.06										

3.2 AHP Method

The Analytic Hierarchy Process (AHP) is a process that converts multidimensional complexity into an integrated single dimension scale of priorities (Choosumrong et al., 2012). AHP method developed by Saaty (1990, 2008) is considered as an effective tool for dealing with complex decision making. Weighting by AHP is widely used in many studies (Mishra, 2013, Choosumrong et al., 2012, Ouma and Tateishi, 2014, Kazakis et al., 2015 and Danumah et al., 2016). AHP aims to resolve conflicts and analyze judgments through a process of determining the relative importance of a set of criteria by pair-wise comparison of these criteria on a 9-point scale (Saaty, 1990). The process of AHP can be summarized in four steps (Ouma and Tateshi, 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 (Table 2). The assignment of the relative significant between criteria is presented in Saaty (1990) with values from 1 to 9 indicating less important to much more important, respectively. In the third step, the relative weights (w_i) of the decision elements are calculated. This step includes calculation of normalized values (NV) for each criterion and determining the principal eigenvectors (or relative weights w_i).

The normalized values for each criterion in the pair-wise comparison (PC) are calculated by dividing the value of each cell by its column total (Table 2). The relative weights are then calculated by averaging the normalized values. 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 (λ_{max}). λ_{max} is calculated by summing the product of each element in the relative weights (w_i) (the Eigenvector) by the respective column total of the original comparison matrix (Vargas, 2010). The calculation λ_{max} are shown in Table 2. The Consistency Index (*CI*) is determined by the equation below:

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

Equation 3

Where λ_{max} is the maximum Eigenvalue of the comparison matrix and *n* is the number of evaluated criteria. In order to verify whether the *CI* is adequate, Saaty (1990) 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:

$$CR = \frac{CI}{RI}$$

Equation 4

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, 1990). When *CR* exceeds 0.1, it is necessary to revise the comparison matrix and re-calculate the weights for better weighting scheme.

3.3 Causative Parameters of Flood

Various data called conditioning factors are needed as independent variables in the process of susceptibility mapping (Liu and De Smedt, 2005). Several authors have developed flood hazard models using multi-parametric approach (Mishra, 2013, Ouma and Tateishi, 2014, Kazakis et al., 2015 and Tehrany et al., 2015). The effective flood model is the one that uses the least number of independent data while still achieving highly accurate results (Tehrany et al., 2014). In this study, five factors were integrated into AHP flood hazard model which are elevation-based flood inundation (EFI), distance from the river channel (DIST), land use (LU), slope and topographic wetness index (TWI). Figure 4 shows the spatial distribution of the normalized parameter ratings (0-10 scale) for the study area.

3.3.1 Elevation-based Flood Inundation (EFI)

Topography is the first-order control on spatial variation of hydrological conditions (Sorensen et al., 2006). DEM represents one of the main causative factors of flooding where lower elevations assume a higher flood hazard potential (Ouma and Tateishi, 2014, Tehrany, 2014, Kazakis et al., 2015 and Tehrany et al., 2015). However, these studies directly applied the elevation information from DEM into the flood susceptibility analysis. In this study, the impact of elevation on flood hazard has been evaluated based on water filling algorithm that is implemented as *r.lake.series* module in GRASS GIS software. The *r.lake.series* model fills a lake or any area from a given start point or river based on the elevation of surrounding areas. The module generates different scenarios of flood inundation containing filled areas for each specified water level which rises from the seeds (river channels). This model is, herein, referred to as Elevation-based Flood Inundation (EFI). The 5m resolution DEM generated by BS-Horizon method and the river channels extracted from 5m RapidEye imagery in March 2014 have been used for building EFI model. The areas which are initially inundated by rising water from rivers pose a higher susceptibility to inundation and can constitute a flood hazard. Based on this analysis, the EFI data has been normalized to different rating (*r*) values which are directly related to flood hazard potential (Table 3). Areas which inundated under 1m water rising have been given the largest rating ($r = 10$). Areas inundated in the case of more than 5m water rising have been assigned minimum rating value ($r = 2$), since there is no field record of flood inundation higher than 5m during past flooding events. Figure 4a shows the distribution of the ratings related to flood hazard corresponding to values of EFI.

3.3.2 Distance from the river channel (DIST)

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 a high weight in AHP flood hazard model. Areas near the river channels are at high risk of flood hazard. The role of river channels decreases as the distance increases.

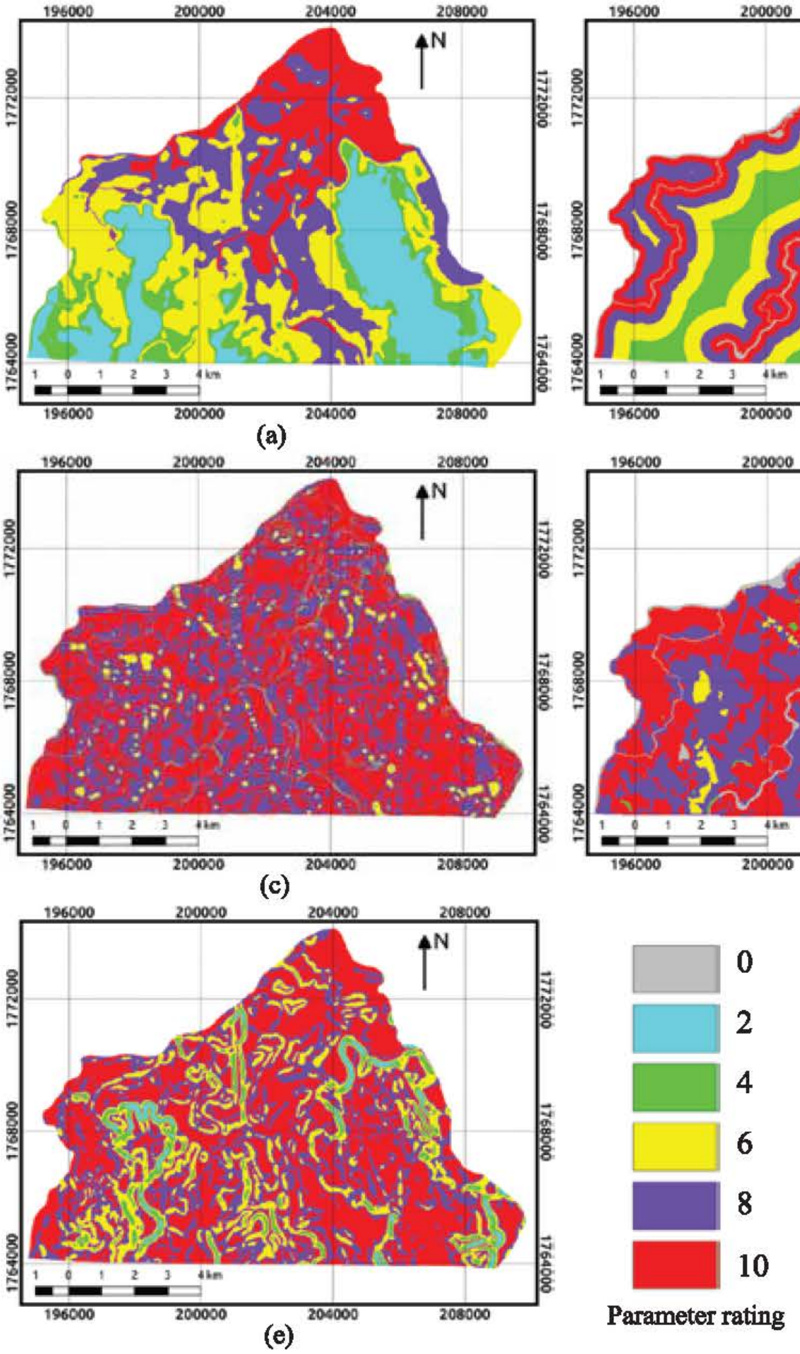


Figure 4: Parameters used in AHP based flood hazard zonation
(a) Elevation-based Flood Inundation (EFI); (b) Distance from the river channel (DIST); (c) Topographic Wetness Index (TWI); (d) Land use (LU); (e) Slope

The classification of distance from the river channel and the corresponding rating values in relation to flood hazard were based on Kazakis et al., (2015). The ratings for the DIST are shown in Table 3. Areas which located in river channels have no flood susceptibility since they are permanent water bodies, with the rating value $r = 0$.

The river channels were extracted from RapidEye satellite image on 2nd March 2014 at 5m resolution. Subsequently, the buffers were generated to categorize distance from the river channel. Figure 4b represents the ratings with respect to flood hazard based on distances from the river channel.

3.2.3 Topographic Wetness Index (TWI)

TWI is calculated using representative points, based on the assumption that the points in the catchment with the same range of TWI will have same hydrologic responses (Bangira, 2013). TWI is defined by the Equation 5:

$$TWI = \ln(a/\tan b)$$

Equation 5

Where, a is the source contributing area and tan$b$ is the ground surface slope. TWI was developed by Beven and Kirkby (1979) within the rainfall-runoff model named "TOPMODEL". The TWI is commonly used to quantify topographic control on hydrological processes (Sorensen et al., 2006) and has been reported as one of driving factors for flood inundation by Tehrany et al., (2015). TWI allows for the delineation of a portion of a hydrographic basin that is potentially exposed to flood inundation by using appropriate threshold (De Risi et al., 2014). The calculations of a in TWI vary in different studies depending on the consideration of source contributing area (Beven and Kirkby, 1979, Sorensen et al., 2006, Bangira, 2013, De Risi et al., 2014 and Tehrany et al., 2015). In the present study *r.topidx* module in GRASS GIS was used (GRASS Development Team, 2016) for calculation of TWI. TWI then was classified into several levels of flood hazard based on the result from Tehrany et al., (2015) and the comparison of TWI data of study area with flood inundation map for 2007. Five categories of TWI and their ratings are presented in Table 3 and Figure 4c.

3.3.4 Land Use (LU)

Land use influences infiltration rate and the interrelationship between surface and ground water (Kazakis et al., 2015). Landsat TM imagery observed on 16th March 2007 has been used for the classification of land use in the study area. Maximum likelihood classification algorithm has been applied in this land use classification. The study area comprises five main types of land use which are agriculture, settlement, bare land, waterlogged and river channel. Waterlogged are low-lying areas where water gets stagnated (Mishra, 2013). The classification of river channel and waterlogged has been verified by RapidEye image in 2014 since the use of Landsat data in 2007 with medium resolution (30m) leads to the inaccurate identification or the discretization of water objects in some areas. Comparison between land use map and flood inundation map extracted from ALOS PALSAR data reveals that the inundated areas are closely related to paddy field or agriculture. Therefore, agriculture land use is considered as having highest inundation potential (r = 10, Table 3). Followed by agriculture, the areas under flood hazard potential are respectively; settlement, bare land, waterlogged and finally river channel. The assignment of weights for land use classes was adapted from Mishra (2013), and the classification result is shown in Table 3 and Figure 4d.

Table 3: Parameters classes, ratings and corresponding weights

Parameter	Classes	Ratings	Weight (w_i)	References
EFI	1m	10	0.42	Tran et al., 2017
	2m	8		
	4m	6		
	5m	4		
	>5m	2		
DIST	200m	10	0.26	Kazakis et al., 2015
	200 – 500m	8		
	500 – 1000m	6		
	1000 – 2000m	4		
	> 2000m	2		
	River channel	0		
TWI	>10	10	0.16	Tehrany et al., 2015
	8.5 - 10	8		
	7.0 - 8.5	6		
	5.5 - 7.0	4		
	< 5.5	2		
LU	Agriculture	10	0.10	Mishra, 2013
	Settlement	8		
	Bare land	6		
	Waterlogged	4		
	River channel	0		
Slope	0.0 - 0.2°	10	0.06	Mishra, 2013
	0.2 - 0.4°	8		
	0.4 - 0.8°	6		
	0.8 - 1.2°	4		
	>1.2°	2		

3.3.5 Slope

Slope influences the amount of surface runoff and infiltration. Flat areas in low elevation may get inundated quicker than areas in higher elevation with a steeper slope (Kazakis et al., 2015). The study area is mostly dominated by the flat topography with slope varying from 0 to 10.5 degree in which 99.9 percent of the area having slope less than 2 degrees. The slope in this study was calculated from 5m BS-Horizon DEM using *r.slope.aspect* model in GRASS GIS software. Adapting the classification scheme for slope proposed by Mishra (2013) with consideration to topographic characteristics of the study area, the ratings for slope are assigned as shown in Table 3 and Figure 4e.

4. Results

4.1 Determining the Weights for Parameters of Flood Hazard

Following the AHP method in determination of relative weights for each parameter of flood hazard, a pair-wise comparison was carried out using a 5x5 matrix. Table 2 shows the criteria of FHI calculation for the study area and their hierarchical comparison. The value of pair-wise comparison (PC) in each row expresses the relative importance of two parameters. The first row of PC in Table 2 illustrates the importance of EFI with respect to the other parameters. For example, EFI was considered of more important than slope and, accordingly, assigned as value 5. Therefore, in the row showing the importance of slope, the comparison to EFI has the inverse values (1/5). This pair-wise comparison was applied for all other parameters as shown in Table 2. EFI has been considered as the most important parameter since flood scenarios derived from this model are the integration between elevations and relations to river channel (seed areas). Distance from the river channel was assigned as the second most important parameter since flood is caused by the overflow of water from river channel and expanding it towards surrounding areas. Therefore, areas closer to drainage network have more risk than the ones far from the river. TWI was considered as the third most important parameter in alignment with relevant studies (Tehrany et al., 2015). Land use and slope were assigned as the factors with lower importance in pair-wise comparison. Following the pair-wise comparison, the normalized values (NV) and the weights (w_i) for each parameter of flood hazard have been calculated (Table 2). EFI was considered as the most important parameter, therefore it has assigned as highest weight (0.42). The corresponding weight for DIST, TWI, LU and slope are assigned 0.26, 0.16, 0.10 and 0.06 respectively. Based on the normalized values shown in Table 2, λ_{max} is calculated as 5.061. In this study, the number of criteria is 5, therefore, n = 5 and RI = 1.12 (Danumah et al., 2016)). According to Equation (4), CI was calculated as CI = 0.015, then the consistency ratio (CR) was obtained as 0.014. Since CR value was smaller than 0.1, the weighting scheme used in this study is considered to be appropriate.

4.2 Flood Hazard Index (FHI) and Flood Hazard Zonation

FHI was calculated based on Equation (1) using the weighting scheme determined by AHP method. The input parameters were normalized into rating values (from r = 0 to r = 10) with respect to flood hazard as shown in Table 3. FHI was measured by summing the product of rating values and the corresponding weights of each parameter. As the result, FHI value ranges from 1.28 to 10.00. The flood hazard zonation map was generated by categorizing the FHI into four classes of flood potential including low, moderate, high and very high (Table 4 and Figure 5). This classification was carried out by observing the histogram of FHI data and considering breakpoints tending to maximize inter-class variance and minimize intra-class variance. Further, flood inundation map in 2007 extracted from ALOS PALSAR was used to revise the thresholds for high and very high potential flood hazard areas. The river channel has been considered as no flood hazard area, since the usual amount of water contained within permanent water bodies does not create a risk for flooding. As the result, 56.3 percent of the study area has obtained the high and very high flood hazard. These areas usually have low elevation (0 to 5m) and are generally located under agriculture (61.5%) and settlement areas (33.4%). 18.6 percent of the area belongs to the moderate zone and 18.7 percent of the area belongs to the low flood hazard zone (Table 4). The remain 6.4 percent of the study area belong to the river channel with no flood hazard.

5. Discussion and Conclusions

Flood pillar points that record depth of previous flood events collected from previous surveys (Do and Nagasawa, 2014) and field trip in 2015 were used for assessing the accuracy of flood hazard zonation map. Result indicated that, 33 out of 37 flood pillar points recording serious inundations are located in high and very high potential of flood hazard. The remaining four pillar points fall into moderate potential area. The high correspondence with field flood pillars reveals the effectiveness of applying AHP method in flood hazard zonation.

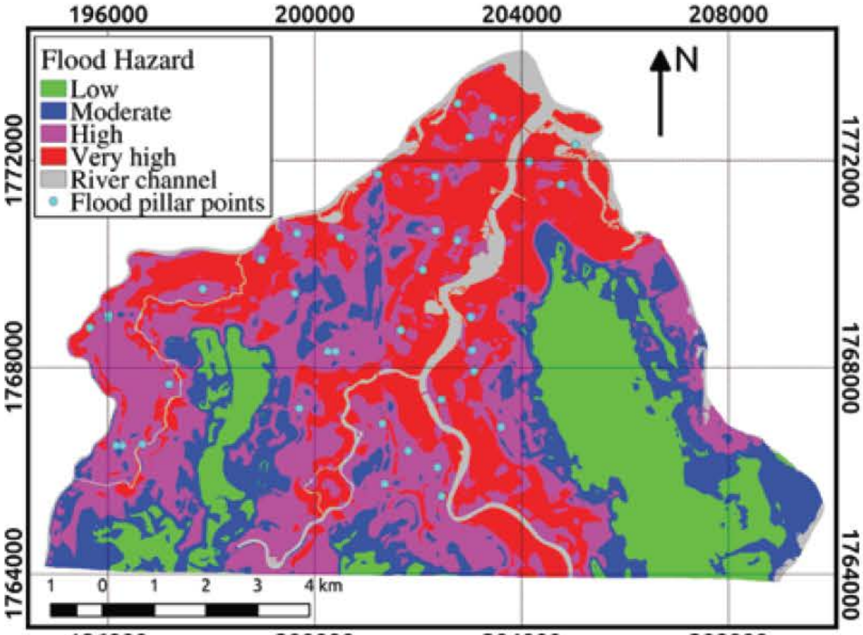


Figure 5: Flood hazard zonation map of the study area

Table 4: Flood hazard zonation based on FHI

FHI values	Flood hazard zones	Percentage coverage (%)
<= 5.0	Low	18.7
5.0 - 6.5	Moderate	18.6
6.5 - 8.0	High	30.6
> 8.0	Very high	25.7

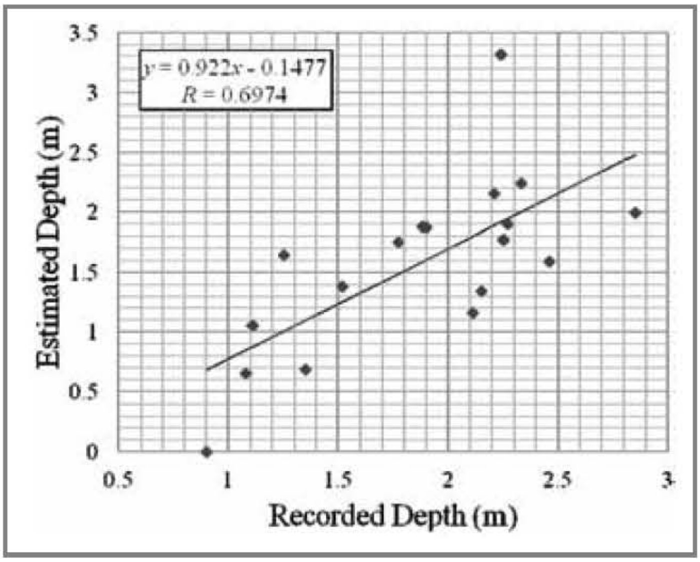


Figure 6: Correlation between estimated and recorded flood depth data in 2007

Further, flood pillars also record the inundation depth during previous flood events 1996, 1998, 1999, 2007, 2009 and 2013. Of the 37 flood pillars located in the study area, only 21 could be verified during the field trip in 2015 and 18 of them show the inundation depth in 2007. The depths recorded for 2007 flood event and output GRASS *r.lake.series* function show high correlation as shown in Figure 6 ($R = 0.6974$).

In addition to comparison with field survey data, flood inundation areas extracted from ALOS PALSAR in 2007 has been used to compare with the flood hazard zonation map. 79.5 percent of inundated areas in ALOS PALSAR image in 2007 belong to high and very high flood hazard zones. This result presents the high agreement between potential flood hazard zones demarcated in this study and the observed inundation during flood event in 2007.

The present study demonstrates the effectiveness of integrating multi-parametric AHP method for flood hazard assessment in lowland area in middle part of Vietnam. This study has evaluated the influence of causative factors and their contribution on flood hazard zonation. AHP method is applied to determine the weights for each parameter and compute the flood hazard index (FHI). Flood hazard zonation map has been generated based on categorizing of FHI into four levels of potential flood. Results of flood hazard zonation in this study revealed good agreement between high potential flood areas and flood pillar points as well as flood inundated areas extracted from ALOS PALSAR data. The proposed method shows the potential of applying AHP method in flood hazard zonation over larger extent when high quality DEM is available.

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