

Environmental Science and Engineering

Phu Le Vo · Dang An Tran ·
Thi Lan Pham · Ha Le Thi Thu ·
Nghia Nguyen Viet *Editors*

Advances in Research on Water Resources and Environmental Systems

Selected papers of the 2nd International
Conference on Geo-Spatial Technologies
and Earth Resources 2022

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Editors

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Preface

In parallel with a remarkable economic growth over the past several decades, the consequences of environmental degradation and resources depletion have placed a paramount challenge on the sustainable development track in Vietnam. Accordingly, in the course of the national rapid socio-economic development, issues of environmental pollution, natural resources management coupled with stresses in the age of global change have increasingly becoming a vital of concern. Therefore, both engineering and management techniques are necessary for environmental pollution control, resources management, and resilience that draw much attention from various stakeholders, including government managers, academia, and industry.

Given this context, we would like to welcome you to the 2nd International Conference on Geo-spatial Technologies and Earth Resources 2022 (GTER 2022), which will be held during October 14–15, 2022, at Hanoi University of Mining and Geology (HUMG), Hanoi, Vietnam. The event is co-organized by HUMG and the International Society for Mine Surveying (ISM) to celebrate the 55th anniversary of the Department of Mine Surveying (HUMG). The conference is financially supported by the Vietnam Mining Science and Technology Association (VMSTA), the Vietnam Association of Geodesy, Cartography and Remote Sensing (VGCR), Vietnam National Coal-Mineral Industries Holding Corporation Limited (VINACOMIN), and Dong Bac Corporation (NECO).

This Volume 2 comprises a series of selected high-quality peer-reviewed papers delivered at the GTER 2022. It provides an in-depth coverage of advanced research in water resources and environmental systems that cover a wide range of topics in recent advanced research in water resources engineering (i.e., surface and subsurface water flow systems, water resources management), advanced techniques and solutions for water and wastewater treatment, water supply and suitable drainage systems, flood modeling and risk assessment, environmental earth systems (i.e., air, coastal, and marine pollution, sustainability and circular economy), applying advanced RS&GIS technologies in natural hazards, monitoring and management for environmental systems such as vulnerability and risk assessment, natural resources, and environmental changes. This critical Volume 2 will bring together, from a global perspective, scientists, researchers, end-users, industry, policymakers from several

countries and professional backgrounds to exchange ideas, advance knowledge, and discuss critical issues for Geospatial Technologies and Earth Resources. It also serves as a valuable reference work for advanced undergraduate and graduate students, designers of water resources systems, and scientists and researchers. The goals of the Volume 2 are: (1) to cover entire water and environmental fields, including hydrogeology, environmental systems, RS&GIS technologies in natural hazard, disaster risks, monitoring and management for environmental systems and geological system; and (2) to employ a multimedia approach to environmental conservation and protection since air, water, soil, and energy are all interrelated.

Totally, 89 abstracts and 50 full manuscripts have been received by the organizing committee. Subsequently, after screening by the scientific committee and reviewing by at least two blind reviewers, 42 research and review papers have been selected to be presented at the conference. The selected papers will be delivered over four planned sessions covering different topics of *Geospatial Technologies*, *Earth Sciences*, *Water Resources*, and *Environmental Systems and Sustainability*. These 42 papers were also selected for publication in this book with Digital Object Identifier (DOI) references. We believe that this book will provide the readers with an overview of recent advances in the fields of Geospatial Technologies and Earth Resources.

We would like to express our sincere thanks to all members of the organizing and selection committees, all blind peer reviewers, all chairpersons, and invited speakers for their invaluable contributions. We are also thankful to Mr. Phuong Kim Minh, President of Dong Bac Corporation; Prof. Tran Thanh Hai, President of the HUMG University Council; Assoc. Prof. Trieu Hung Truong, Vice-rector of HUMG for their administrative work and financial supports. Special thanks are also to Doris Bleier and Viradasarani Natarajan at Springer Nature for their helpful assistance and support throughout the procedures of this book production. Finally, all authors are thankful for their manuscript submissions regardless of whether or not their manuscripts were selected.

Hanoi, Vietnam
June 2022

Phu Le Vo
Dang An Tran
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Ha Le Thi Thu
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Chapter 35

Flash Flood Hazard Mapping Based on Analytic Hierarchy Process for a Complex Terrain: A Case Study of Chu Lai Peninsula, Vietnam



Thi Lan Pham , Si Son Tong , and Viet Nghia Nguyen

Abstract Flooding prediction for a large scale area has been popularly carried out, nevertheless flood hazard assessment for a small, complex terrain for planning industrial constructions needs more detailed studies. This study aims to: (1) determine forcing factors and their roles in the flood hazard using the Analytic Hierarchy Process (AHP), and (2) generate the flood hazard map using spatial analysis in Chu Lai peninsular, Vietnam. The study shows that 6 important forcing factors on flood hazard include drainage density, infiltration rate, soil saturation, elevation, slope, and land cover. The factor which most impacts on the flood hazard is the elevation with the detected weight of 0.438. The infiltration rate plays the least importance with a weight of 0.066. Consequently, a flood hazard map is generated with 5 levels very low, low, medium, high, and very high hazard of flood. The very high hazard occupies 7.16% area of the peninsula focusing on the regions covered by concrete surface, permanent and temporal water cover, bare soil, and very low slope from 0° to 8°. The map provides critical information to make a plan for one of the most important industrial complexes in the center of Vietnam.

Keywords AHP · Flood hazard · Chu Lai

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35.1 Introduction

Floods are the most frequent type of natural events. Flood events occur every year worldwide. Vietnam is one of the countries that has suffered strongly from negative effects because of a flood. There are about 196 million people in more than 90 countries that are exposed to catastrophic flooding (Karki et al. 2011). Recently, floods in Vietnam occur regularly with severe consequences such as great loss of life, property, and facilities Infrastructure. The Chu Lai peninsula, Vietnam is located in Nui Thanh district, Quang Nam province. Its geographical setting and geomorphologic and climatological conditions make it prone to several types of natural disasters such as floods, landslides, and wind storms. Among these, floods have been identified as the most frequent natural disaster that savages the economic and social activities of the affected areas. Therefore, it is necessary to establish a flood hazard map to ensure healthy and sustainable economic development, and flood hazard assessment has become worldwide one of the hot issues in the field of natural science and technology (Zou et al. 2013). The mapping can be linked to formulating policies for disaster reduction. It is also an advantage for the community and decision-makers to prepare and implement effective measures (Elkhrachy 2015). Climate change projections for 2030 indicate that the number of people exposed to flooding will increase [source: (Parsian et al. 2021)]. There are different approaches to establish flood hazard maps, including geomorphological, historic, and remote sensing (Díez-Herrero et al. 2009). To select an appropriate method, the availability of relevant data is the most critical element. Remote sensing data can be an adaptive data source (Koem and Tantane 2020). Remote sensing methods are usually more effective for flood hazard mapping because remote sensing data are acquired frequently with various spatial resolutions and cost-effective. However, the acquisition of aerial photographs or satellite images is limited by weather conditions. Therefore, the image of unmanned aerial vehicles (UAV) is becoming increasingly popular due its flexibility (Karamuz et al. 2020). The UAV image is used to extract land cover, elevation and slope. The flood hazard information is determined by appropriate and sufficient criteria. Several studies determined the flood hazard mapping using multi-criteria analysis (Koem and Tantane 2020; Hoque et al. 2019; Bathrellos et al. 2016; Nguyen et al. 2021). Analytical Hierarchy Process (AHP) is one of the most useful approaches of MCA in the field of flood hazard evaluation (Koem and Tantane 2020). Impact factor layers are analyzed in the AHP environment that provides weighting and ranking with the guidance of experts and users (Fernandez et al. 2015). However, AHP has been proposed to apply for flood hazard mapping at the region level. In previous research, it was difficult to find a detailed flood hazard mapping in a small complex terrain. This study aims to evaluate a multi-criteria-integrated approach to establish detailed flood hazard mapping using AHP incorporating information produced from UAV images and spatial analysis integrating GIS. This study proposes the integrated AHP and spatial analysis encompassed six parameters in the flash flood hazard assessment: drainage density, infiltration rate, soil saturation, elevation, slope, and land cover.

35.2 Study Area

The survey area belongs to Tam Quang commune, Nui Thanh district, which is located to the South of Quang Nam province. The North borders Ky Ha port, and the South borders Chu Lai airport, the West borders the center of Nui Thanh District, and the East borders the East Sea (Fig. 35.1).

In general, Tam Quang commune has hilly terrain along the coast. The area is flat and low, with stable sand dunes; a part of the delta is deposited by rivers on the sand. This region is located to the east of the Truong Giang River. Sandy soil occupies the largest area in the soil composition of this area. Also, this area has many sedimentary rocks protruding from the sea surface from 10 to 12 m in the commune such as the islands of Ngang, Hon Dua, and Ban Than.

In the survey area, the average annual temperature in the coastal plain ranges from 25.5 to 26 °C. The yearly average wind speed in the coastal plain is 1.3–1.6 m/s. The highest wind speed reaches 34 m/s in the dry season and 25 m/s in the rainy season.

Storms that occur in the area are usually formed from the South China Sea, moving into the area slowly, and the wind speed is low due to the high mountains of the Truong Son mountain range. High winds, and typhoons focus on low-lying areas, which is also the cause of flooding in downstream areas. In upstream areas, floods appear and withdraw very quickly, and flash floods often occur during the rainy season. In Quang Nam province, the rainy season usually takes place from late September to

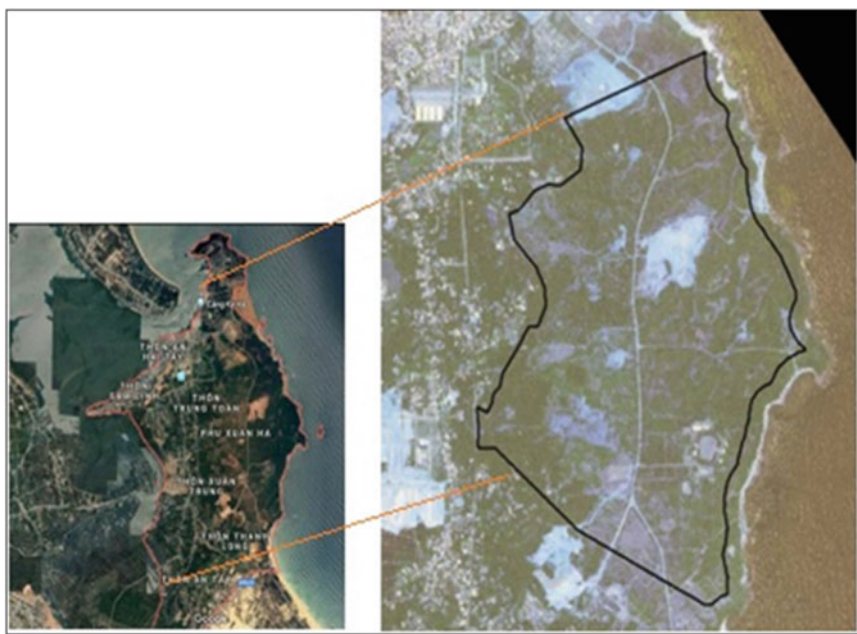


Fig. 35.1 Location of the survey area

December, the dry season is from January to August every year. In particular, there are two months in the dry season that often have heavy rains, which are May and June every year.

The river system in the study area includes Tuc river, An Tan river, and Trau river. These rivers originate from the west, the northwest. They flow to the east and reach into the sea through An Hoa and Lo estuaries. All rivers have small basins, from 50 to 100 km², with significant slopes, from 20 to 40 km in length, and the water flow varies with the seasons. The amount of water in the rivers is abundant in the rainy season from September to December and drought in the dry season from February to August. Some rivers are prevented from being upstream to make reservoirs such as Phu Ninh Lake on the Tam River. Ky and Thai Xuan lake on Trau River, of which Phu Ninh Lake is a major irrigation project of Vietnam, responsible for irrigating 20,000 ha of rice in coastal districts south of the Thu Bon River as well as supplying domestic water to Tam Ky and surrounding areas. The downstream river has wetland ecosystems in Tam Quang, Tam Anh Nam, Tam Anh Bac, Tam Hoa, Tam Giang, Tam Hai, and Tam Tien communes. No rivers are flowing through the study area. But numerous small streams and trenches flow from the center of the study area to the east and west of the survey area.

35.3 Data and Methodology

35.3.1 Data

The assessment of the flash flood hazard required the data of dynamic criteria, including UAV image, soil (rate of soil permeability and saturation of soil), hydrology (drainage density) and terrain (elevation and slope). We used data from various sources for creating spatial criterion layers using geospatial techniques. The list of data used for flood hazard assessment is shown in Table 35.1.

Table 35.1 List of data used in flash flood hazard assessment of Chu Lai peninsula

No	Name of data	Date	Type (format)	Sources
1	Drainage system	2019	Shape file	Blue whale project, PVE company
2	Watersheds	2019	Shape file	Blue whale project, PVE company
4	UAV image	30/11/2019	Tiff file	Blue whale project, PVE company
5	Soil permeability	30/11/2019	Text file	Blue whale project, PVE company
6	National ground control points	30/11/2019	Text file	Field observation

The WGS 1984 UTM with the coordinate system of zone 48 was projected for all impact factor maps in this paper. The UAV image was used to extract land cover and create a digital elevation model (DEM). Field measurement data, UAV orthoimages, and DSM produced by UAV images are used to produce the land cover map. Field measurement provides information about land cover classes existing on the field, the samples for the classification. Moreover, field data gives the global view and the ideas to construct the theme of the land cover map as well. The extremely high-resolution orthoimage acquired by the UAV technique is the good condition to determine accurately the edges of land cover classes. The DSM simulates the elevation of all objects such as the rooftop of houses, tree canopy. Elevation information from the DSM is used to recognize the difference between objects related to relative height as high trees and lower trees, dense shrubs, and grass. DEM was used to build slope and elevation map spatial analysis methods in GIS. The data of soil is provided by the Blue whale project, PVE company with 63 locations of infiltration rate and 26 positions of soil saturation. The spatial analysis method was used to establish soil permeability and saturation map. Finally, the hydrology system is interpolated to create drainage density.

35.3.2 Methodology

Methodology for flood hazard mapping hazards can be seen in Fig. 35.2. There are four main steps in this process such as the data collection of impact factors, natural break classification, process AHP and building flood hazard map.

35.3.2.1 Impact Factors of Flood Hazard in Chu Lai Peninsula, Nui Thanh District, Quang Nam Province, Vietnam

The definition of the impact factor of a flood potential is crucial. There are many factors that contribute to flood hazard, but the study focuses on the criteria of physical geography hazard. The impact factor of flood potential includes two conditions: (1) prerequisites including precipitation reaches the maximum that it causes flow strongly. (2) Sufficient conditions such as topography, geomorphology, watershed, pedology, land cover, the drainage system, and soil permeability.

The selection of factors affecting flood hazard depends hazard on the study area. According to Dung et al. (2021a), there are six group of the criteria leading to the formation of a flood, namely (1) criteria related to hydrological and orographic characters; (2) factors related to the geomorphologic character; (3) parameters related to the meteorological character; (4) elements related to cover characters; (5) factors related to soil characteristics; (6) variables related to infrastructure and socioeconomic characters (Dung et al. 2021a). Most studies used expert methods or Delphi

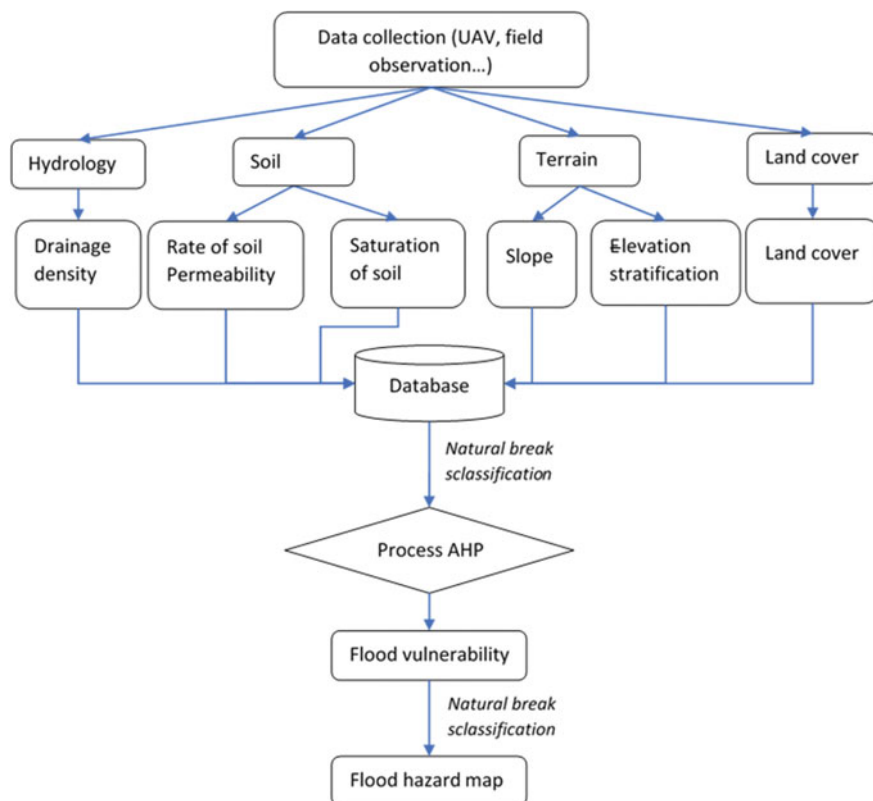


Fig. 35.2 Flowchart of the methodology

methods to determine criteria affecting flood formation (Dung and Tuyet 2021; Dung et al. 2020). However, impact factors are used widely including slope, precipitation, land cover, drainage, stream density, and soil permeability (Nguyen et al. 2021; Dung et al. 2021b).

Chu Lai peninsula located in Nui Thanh district, Quang Nam. The peninsula covers an area of 340 ha and distributes the same amount of precipitation. Thus when determining potential flood, we will not care about precipitation.

In conclusion, there are six impact factors for flood hazard in the Chu Lai peninsula including elevation stratification, slope, land cover, drainage density, infiltrate rate of the soil, and saturation of the soil.

35.3.2.2 Classification of Factors Affecting Flood in Chu Lai Peninsula, Nui Thanh District, Quang Nam Province, Vietnam

In this study, impact factors classification comprises six parameters: Drainage density (Dd), Rate of soil permeability (Ps), Saturation of soil (Sa), Slope (SI), Elevation stratification (EI) and Land cover (Lc). These parameters have been manipulated in GIS using natural break classification with five risk levels namely very low, low, medium, high and very high risk zones of flood. The physical parameters are assigned values 1, 3, 5, 7, and 9 respectively as rating scores. The rating scores have been used in the calculation of the relative significance of each criterion as a pairwise matrix comparison to produce corresponding weighting factors (w).

1. The classification of land cover affecting to flood hazard

The ability to influence flood hazards of land use and land cover will vary for different geographic areas.

According to Tehrany, rain-water on bare land will be stronger than on agricultural land and plantation forest. In the Residence area, urban areas with impervious surveys will have more intense flow than the regions covered by vegetation and woodland (Tehrany et al. 2013). This indicates that the hazard of flooding will be higher in vacant areas and residential areas than in areas covered with vegetation, forests or agricultural land.

This conclusion was also proved in the study (Tehrany et al. 2013) with the frequency (frequency) (FR) floods in the non-vegetated bare land areas being the maximum and the dense areas with FR value will be the minimum. In many studies, the authors have classified the hazard of affecting land cover on flood hazard in ascending or descending order based on the above analysis.

In Yasooj, Iran, Rahmati said that the most vulnerable land to floods is the river zone, the second is residential land and roads, followed by vacant land, agricultural land, and finally forest land at hazard (Rahmati et al. 2016). The influence of land cover on flood hazard in the Kassandra Peninsula, Greece was divided into three levels according to influence from low to high in the following order: forest land, shrubs, and grasslands, agricultural land. And vacant land (Stefanidis and Stathis 2013). According to Sekac, Jana and Pal, the influence of land cover on the hazard of flooding decreases gradually in the order of water surface land, bare land, construction land, agricultural land, open forest, dense forest (Sekac et al. 2015).

Detail the ability to affect the flood hazard of land use and overlay factors in a study (Elkhrachy 2015), the author assessed that the water surface is most at hazard of flooding, followed by wet soil, urban land, industrial parkland, agricultural land, land with sparse vegetative cover, grassland and finally forest land. Besides the land cover, the type of forest and its quality also affect the potential flood. According to Ngo Dinh Que, forest cover in the basin is an important indicator to manage water resources in the basin in a rational and sustainable manner. When the forest cover is low, the water regulation capacity of the forest in the basin is poor, so in the rainy

season, the water flow in the river basins will be large and concentrated so it is easy to cause floods (Que 2011).

Thus, the water regulation capacity of multi-storey, high coverage forest (rich and medium forests) is better than that of planted forests, bamboo forests and natural forests with low coverage, low canopy floors (poor forest). In addition, because the permeability under the forest canopy is often higher than the condition covered by shrubs, the possibility of generating groundwater flow is much lower than that of the shrub (Dung 2016). It means that the forested area is less likely to be flooded than the area covered by shrubs. The greater the level of the impact on flood hazards is the lower the capacity to retain water and protect the land of different land cover/land use types. According to the above statements, the land covers affecting flood potential are stratified into 5 levels and they are assigned with values 1, 3, 5, 7, 9 as seen in Table 35.2 and Fig. 35.3.

2. The classification of slope effecting to flood hazard

It is necessary to classify the slope according to the level that affects the hazard of flooding. Some flood hazard studies show that it depends on the largest and smallest slope in the study area. These studies stratified the slope into an equal interval as 3°, 5°, 9°, 18° (Saini and Kaushik 2012; Schultz 1995; Ouma and Tateishi 2014). Besides, the slope is lower the hazard of flood is higher (Moglen et al. 1998; Kazakis et al. 2015). The slope was separated into 5 levels:

- Flat area (<3°)
- Low slope (3°–8°)
- Medium slope (8°–15°)
- High slope (15°–25°)
- Steep slope (>25°).

The classification of slope is suitable for the geographic characteristics of the study area. Thus, with 5-level sloped terrain in the study area, the area with the lowest slope is considered to have the lowest flood hazard, and vice versa, the region with the highest slope will have the highest flood hazard (Van Hoan et al. 2019; Costache et al. 2021; Shawaqfah 2020). It means that the more flood hazard increases, the

Table 35.2 Hierarchy of land cover effecting to flood hazard

No	Land cover	Mark	Level of flood hazard
1	Dense shrubs, Acacia trees	1	Very low
2	Eucalyptus trees, coniferous trees, spare shrubs, grass	3	Low
3	Resident area, construction, cemetery	5	Medium
4	Bare land, concrete surface, roads, laterite holes	7	High
5	Temporal water, permanent water, sandy area	9	Very high

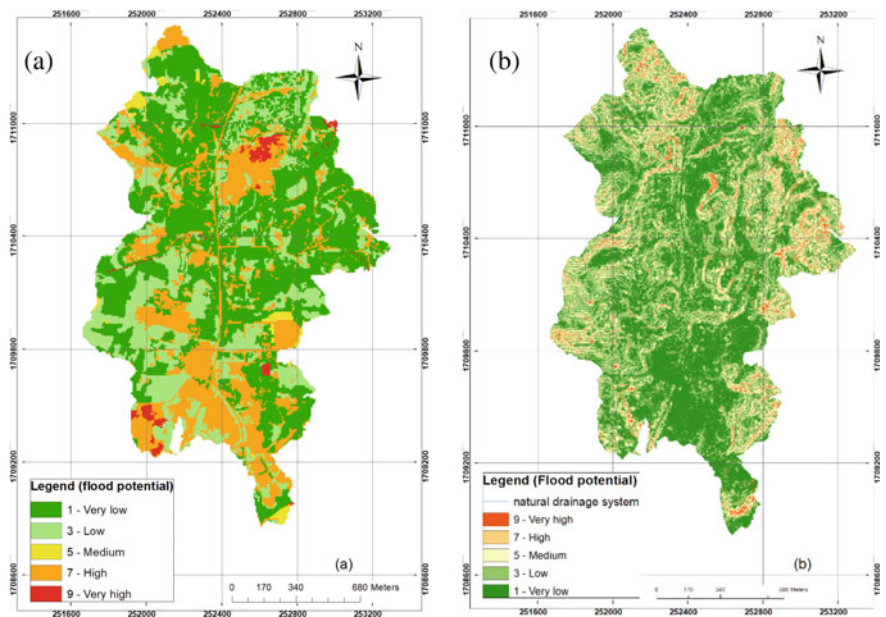


Fig. 35.3 Map of land cover (a) and slope (b) effecting to flood hazard

more slope rises, and the score corresponding to the level of influence will vary from 1 to 9 as shown in Table 35.3 and Fig. 35.3.

Using Digital Terrain Model—DTM (DTM is provided by Contractor) and spatial analysis methods to do slope interpolation. The resolution of the DEM determines the accuracy and detail of the slope map. However, because ArcGIS software interpolates and assigns the range of slope values automatically, the values of the slope thresholds do not match the standard slope scale. Therefore, in order to classify the gradients in accordance with the requirements, it is necessary to reclassify with the Reclassify tool.

Table 35.3 Hierarchy of slope effecting to flood hazard

No	Slope	Mark	Level of flood hazard
1	>25°	1	Very high
2	15°–25°	3	High
3	8°–15°	5	Medium
4	3°–8°	7	Low
5	<3°	9	Very low

Table 35.4 Hierarchy of elevation stratification affecting to flood hazard

No	Elevation stratification (m)	Mark	Level of flood hazard
1	37–52.54	1	Very low
2	28–37	3	Low
3	25–28	5	Medium
4	15–25	7	High
5	–0.5–15	9	Very high

3. The classification of elevation stratification affecting to flood hazard

Elevation stratification has a significant impact on environmental modeling. Several studies have also been done to demonstrate the effect of the DTM characteristics in hydrological studies.

There are seven methods to reclassify DTM: manual interval, defined interval, equal interval, quantile, natural breaks, geometrical interval and standard deviation. These methods were tested for creating the DTM of the study area. The natural breaks method is used for this work because its result well represents the distribution of topographic stratifications. The Digital Terrain Model (DTM) of the study area is reclassified to five levels which show the level of flood hazard in the following Table 35.4 and Fig. 35.4.

4. The classification of drainage density affecting to flood hazard

The drainage density relates to the runoff and the gathering water potential as well. The natural breaks method was used to create the hierarchy of drainage density affecting flood hazard because it produces the most appropriate results compared to other methods. The levels of flood hazard caused by drainage density are shown in Table 35.5. Figure 35.4 illustrates the effect of drainage density on flood potential. The drainage density is calculated for each pixel with the size of 1 m². In regulation, the higher the value of drainage density is, the amount of water simultaneously gathering in the area of pixel size is. Thus, the floods tend to occur in the area with higher drainage density. In this case, the flood develops in a gradual ponding or build-up of water in low-lying, flood-prone areas as well as creeks and streams.

5. The classification of Soil (soil permeability rate and soil saturation) effecting to flood hazard

Soil permeability data can provide an early warning of soil degradation, flood hazard, and erosion. In this study, we use two parameters of soil to assess flood-prone areas such as infiltrate rate and saturation. The higher the permeability of a soil layer, the faster water can infiltrate through and avoid flooding. In addition, the higher the saturation of the soil, the lower the flood potentialis. The rest area is equally divided into four particle-size classes (Clay; Clay Loam; Loam and Sandy Loam)

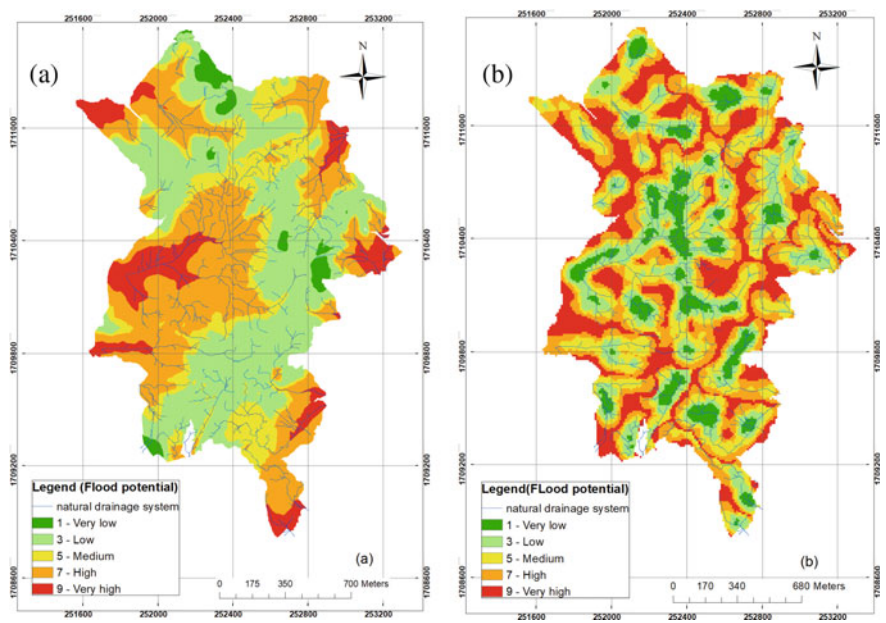


Fig. 35.4 Map of elevation (a) and drainage density (b) affecting flood hazard

Table 35.5 Hierarchy of drainage density affecting flood hazard

No	Drainage density (m/ha)	Mark	Level of flood hazard
1	0.031–0.065	1	Very high
2	0.021–0.031	3	High
3	0.013–0.021	5	Medium
4	0.004–0.013	7	Low
5	0–0.004	9	Very low

with infiltration rate varies from 0.2 to 2.5 cm/h (source: Report on the results of soil permeability and infiltration rate). Table 35.6 shows the hierarchy of infiltrating rate and saturation affecting flood hazard. The hierarchy of infiltrating rate is based on the regulation that the higher particle size is the lower level of the flood potentialis (Table 35.6). The soil saturation tends to affect the flood potential in the linear negative trend thus the equal interval separation method is used to build the hierarchy of soil saturation (Table 35.6) (Fig. 35.5b).

Table 35.6 Hierarchy of infiltrating rate and saturation of soil affecting to flood hazard

No	Permeability rate (distribution of infiltration rates for certain particle-size classes)	Saturation	Mark	Level of flood hazard
1	Sand	75.08–93.86	1	Very low
2	Loam	56.31–75.08	3	Low
3	Sandy loam	37.54–56.31	5	Medium
4	Clay loam	18.77–37.54	7	High
5	Clay	0–18.77	9	Very high

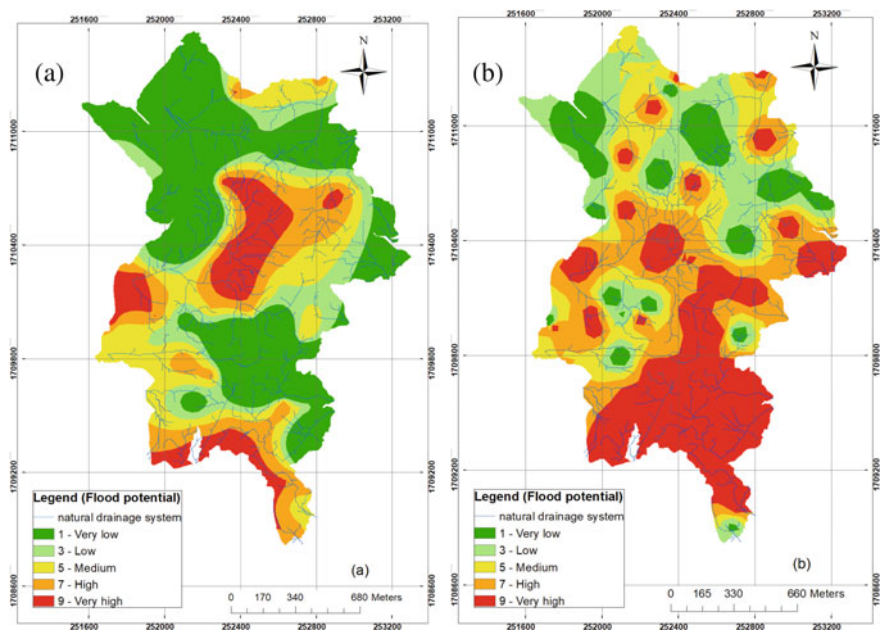


Fig. 35.5 Map of infiltrating rate (a) and saturation rate (b) of soil affecting flood hazard

35.3.2.3 Analytical Hierarchy Process (AHP)

Flood hazard is formed and developed by the impact of many factors, this section refers to six factors that the author assessed as the main factors. With the use of AHP, the study was able to obtain a relative significance of the relevant factors after the pairwise-comparison matrix have been constructed. Impact factors of flood hazard have different roles, so a quantitative assessment of the importance of the influencing factors is necessary. This paper assesses with the determination of weights, based on statistical results analysis of architectural components or based on the knowledge of experts.

Table 35.7 The scores of a pairwise comparison matrix (Saaty 1980)

Scale	Meaning
1	Equally more important (EQ)
3	Moderately important—WeaKly more important (WK)
5	Important—STrongly more important (ST)
7	Very strongly more important (VS)
9	Extremely important—ABSolutely more important (AB)

Table 35.8 Pairwise comparison matrix

	Land cover	Slope	Elevation	Drainage density	Permeability rate	Saturation
Land cover	1	1/7	1/7	7	9	9
Slope	7	1	1/7	1	1/3	1/3
Elevation	7	7	1	7	9	9
Drainage density	1/7	1	1/7	1	5	1/3
Permeability rate	1/9	3	1/9	1/5	1	1
Saturation	1/9	3	1/9	3	1	1

For each criterion, a pairwise comparison matrix is created. The scores to be used in the matrix are based on the Saaty scale (1980) as shown Table 35.7:

The pairwise comparison matrix is shown in Table 35.8 using a 6 × 6 matrix, where diagonal elements are equal to 1. The values of each row are compared with each column to define the relative importance to obtain a rating score. For example, Table 35.2 shows that elevation is significantly more important than slope and therefore assigned the value 7. Row describes the importance of slope. Therefore, the row has the inverse value of the pairwise comparison (1/7).

The consistency of the created eigenvector matrix for AHP needs to be evaluated. The required level of consistency is evaluated using the following index:

The consistency index (CI) is calculated using Eq. (35.1) where calculated $\lambda_{\max}$ = 6.57.

$$CI = \frac{Y_{\max} - n}{n - 1} \tag{35.1}$$

where: the number of parameters (n = 6)

$Y_{\max}$ the maximum Eigenvalue

$$C.I. = 0.114;$$

Table 35.9 Weights of factors

Evaluation items	Weights
Land cover	0.19
Slope	0.16
Elevation	0.44
Drainage density	0.06
Rate of soil permeability	0.07
Saturation of soil	0.08

We then determine the consistency ratio (CR) by the formula:

$$CR = \frac{CI}{RI} \quad (35.2)$$

where

CR the consistency ratio
 CI the consistency index
 RI random index (1.7).

Eventually, the calculated consistency ratio is 0.07 that is lower than the threshold of 0.1, the weights' consistency is affirmed and the weights are acceptable (Table 35.9).

35.4 Results

After developing the impact criteria maps, and determining the weight of the factors affecting the flood, building maps of flood hazard zoning by spatial analysis method in the GIS environment. It is the integration of the component maps (map of impact criteria) based on the general equation for calculating the hazard score according to the hierarchical point of each element and the weight of each specific element. Determination of potential flooding in the Chu Lai peninsula was calculated using the Map Algebra in ArcGIS

$$Y = 0.19 * Lc + 0.16 * Sl + 0.44 * El + 0.06 * Dd + 0.07 * Ps + 0.08 * Sa \quad (35.3)$$

where

Lc Land cover
 Sl Slope
 El Elevation
 Dd Drainage density

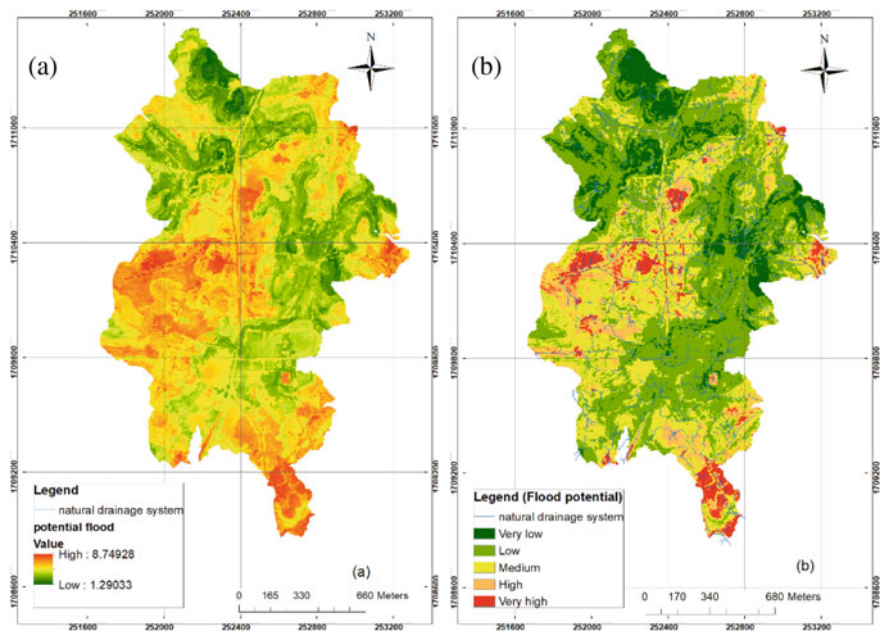


Fig. 35.6 Map of flood hazard (non-stratification) (a) and map of flood hazard stratification in Chu Lai peninsula (b)

- Ps Rate of soil permeability
Sa Saturation of soil.

The flowing Fig. 35.6 shows the value of flood potential in the Chu Lai peninsula. Assessment flood-prone needs to classify the flood potential into five classes. In this study, there was a significant leap between the frequency of very low potential value and the frequency of the very high potential value. Thus we use the natural breaks classification method to reclassify the flood potential as shown in Table 35.10. Besides, Fig. 35.6 illustrates the flood potential in Chu Lai Peninsula, Nui Thanh, Quang Nam.

Figure 35.6 shows that the flood potential is predominated by low and medium potential classes. The low flood potential ranged 3.6–5.08 covers 34.68% of the whole

Table 35.10 Stratification of the flood potential area

Number	Mark of potential flood	Class	%
1	0–3.60	Very low	13.88
2	3.60–5.08	Low	34.68
3	5.08–5.97	Medium	27.83
4	5.97–6.77	High	16.45
5	6.77–9.0	Very high	7.164

area (Table 35.10). Four other classes medium, high, very low, and very high flood potential occupy 27.83%, 16.45%, 13.88% and 7.16%, respectively. These numbers indicate that most of the Chu Lai peninsula area has a low vulnerability to floods. Flood events are concentrated in certain areas only. The very high and high potential floods have small area where distribute land covers composing of spare shrubs, residents, concrete surface, bare land, laterite holes, eucalyptus trees, temporal water and permanent water. The area with very low and low slope, high drainage density, and the low elevation of less than 15 m are also available for high flood potential. The area of the medium flood potential is relatively large. The vegetation of these areas is spare shrubs, dense shrubs, concrete surface, bare land, acacia trees, and eucalyptus trees. In addition, the areas have medium slope and elevation. Besides, most of the study area is very low and low flood potential where are covered by spare shrubs, dense shrubs, bare land, and acacia trees.

In sum, the flood potential strongly depends on the elevation (0.437991 affecting weight), the land cover and the slope with the affecting weight of 0.192821 and 0.158047, respectively. Whereas, the drainage density, infiltration rate and saturation of soil insignificantly affect the flood-prone.

35.5 Conclusions

This study presents a multi-criteria-incorporated approach of spatial flood hazard mapping using UAV images, spatial analysis and field data at a detailed scale. The UAV was used to extract land cover and DEM. Geospatial techniques were used to map all selected criteria under each component of hazard flood. The AHP model was applied to integrate multi-criteria in a spatial decision-making process. The Chu Lai peninsular, Vietnam was used for examining the suitability of the method.

A detailed scale study integrated with multi-criteria evaluation is required to achieve accurate and detailed flood hazard information. However, collecting spatial data at the detail scale is highly challenging. The AHP was a useful model for weighting the selected multi-criteria and spatial decision-making process. This paper presented a framework for the overall spatial flood hazard assessment that integrates six impact factors. The generated information from this study could be applied by planners and administrators to develop effective flood effect mitigation strategies.

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