The Importance of Relative Slope Length Data in Flood Hazard Zoning: A Case Study of the Ngan Sau, Ngan Pho River Basin, Vietnam

Tuyet Minh DANG[1], Duyen Quang LE[2]*, Ba Dung NGUYEN[3]

[1] Thuyloi University, 175 Tay Son street, Ha Noi, Vietnam; ORCID: https://orcid.org/0000-0001-8379-1087
[2] Hanoi University of Mining and Geology, Hanoi, Vietnam; ORCID: https://orcid.org/0000-0001-6953-4762
[3] Hanoi University of Natural Resources and Environment, Hanoi, Vietnam; ORCID: https://orcid.org/0000-0001-5378-0926
* Corresponding author: Duyen Quang LE, email: lequangduyen@humg.edu.vn

http://doi.org/10.29227/IM-2024-01-89

Submission date: 22-05-2024 | Review date: 01-06-2024

Abstract

Flood modeling provides useful information to assist manage flood hazards and lessen the effects of floods in locations that are vulnerable to flooding. The present research established flood hazard maps for the Ngan Sau, Ngan Pho river basin using GIS technology and the Analytical Hierarchy Process (AHP) method. The precision of flood simulation results is dependent on criteria that cause flooding. The goal of this study was to evaluate the role of relative slope length in flood hazard identification and delineation. The AHP method was used to determine the respective weights of six physical geography and meteorology factors including rainfall, slope, soil, land use, drainage density, and relative slope length. In the process of computing the model, these factors are classified into two groups: group 1 includes five criteria excluding the relative slope length criterion and group 2 has all six parameters. Based on flood warning levels at hydrological stations in the research area during past floods, the results of flood hazard zoning were verified. The obtained findings indicated that map developed from the group of criteria including the relative slope length are more accurate than those generated based on the remaining five factors. The results of the paper can be used as a reference when choosing criteria for creating flood hazard zoning models utilizing a combination the AHP and GIS technology.

Keywords: *Analytical Hierarchy Process, AHP, flood hazard, relative slope length, Ngan Sau, Ngan Pho river basin*

1. Introduction

The flood is one of the most devastating disasters affecting human's lives and the ecosystem, causing both life and material damage. The determination of the flood hazard is a necessary pre-requisite for flood risk evaluation [1]. Moreover, flood hazard map play an important role in assessing susceptibility of flood prone area, estimating the spatial extent of flood and flood depths [2]. To detect the flood potential areas, a variety of techniques, approaches, and models have recently been developed and implemented. With the development of satellite technology, geographic information system (GIS) and remote sensing images have gradually taken precedence to delineate flood potential regions [3]. In addition, flood hazard map can be generated by using various machine learning models, namely, random forest, support vector machine, gradient boosting model, decision tree, classification regression tree, and naïve Bayes [4]. Recently, several research have utilized Multi-Criteria Decision Analysis (MCDA) like the Analytical Hierarchy Process (AHP) to evaluate the possibility for flood hazard [5, 6]. The AHP algorithms can integrate with Delphi methods to assess the impact level of criteria on flood hazard [7]. In addition, this approach used in various fields such as groundwater [8], agriculture [9, 10], land slide [11], drought [12], etc. Their findings showed that AHP is the most widely used and effective method for creating accurate flood hazard maps in the GIS environment, and it is also appropriate for other hazard studies. Many scientists described AHP as an easy-to-use, affordable, and convenient approach for flood risk assessment. In particular, this approach can be applied for a large and complex river basin with data sparsity [13].

According to Dung et al. (2022), floods occur due to several reasons such as hydrological, orographic, geomorphologic, meteorological, cover, soil, infrastructure and socio-economic factors [14]. The relationships between flood hazard and these conditioning parameters have been studied by researchers. Many publications indicated the factors that have significant influence on flood potential including rainfall, slope, drainage density, soil, land cover, land use, etc. Although the slope length factor contributes significantly to flood formation, it has not been mentioned much. There were many research used this factor and most of them assessed that slope length plays an important role in sediment yield by rainfall impact of various land use types [15], soil loss for steep slopes [16], the size distributions of loess slides [17], runoff and erosion conversion [18], soil erosion [19], sediment concentrations [20], flood hazard [8, 21]. In most erosion studies, this factor is used in conjunction with the slope angle or slope gradient and is referred to as LS-factor. However, for flood hazard studies, slope length is used independently with other factors contributing to flood generation to develop the flood hazard model, such as rainfall, slope, drainage density, land use, soil, etc. Literatures found that slope length was strongly correlated with runoff [22]. According to Verrina et al. (2013), runoff is part of the precipitation that falls over the surface of land to bodies of water like lakes, rivers, ocean, etc. An increase in runoff volume is the cause of flooding problems in the downstream watershed [23]. Therefore, it is undeniable that, slope length has a significant contribution to flood hazard.

In this study, the slope length factor was applied to simulate the flood hazard index using AHP method in Ngan Sau,

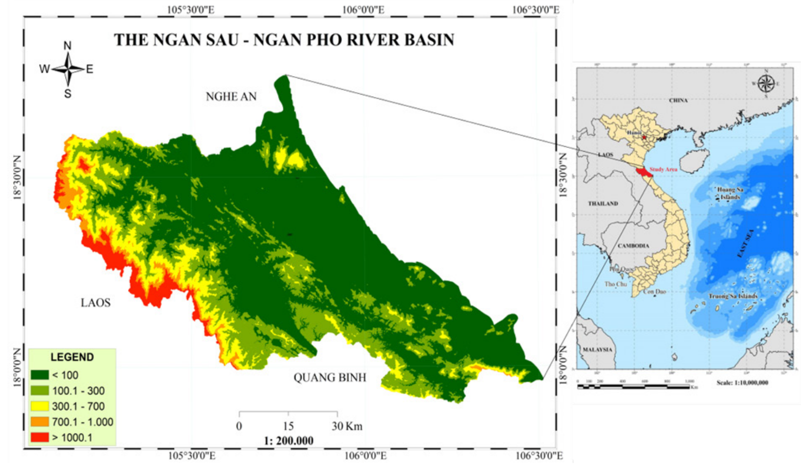

Fig. 1. The Ngan Sau – Ngan Pho river basin, Vietnam

Rys. 1. Dorzecze rzek Ngan Sau – Ngan Pho, Wietnam

Ngan Pho river basin. Flood hazard map generated from slope length and others was verified by the historical flood events. Accordingly, the important role of the slope length factor will be confirmed when establishing flood risk zoning maps using the AHP approach for the study area as well as other geographical regions.

2. Study area

The study area is in the North Central of Vietnam. It is located at longitudes of 105°07´00"E to 106°56´00"E and latitudes of 17°50´00"N to 18°37´58"N. The Ngan Sau, Ngan Pho river basin has an area of approximately 2061 km2 and 1065 km^2 respectively consisting of Huong Son, Huong Khe, Vu Quang, Duc Tho districts [24, 25], as shown in Figure 1. The Ngan Pho River is the largest tributary of the La River, originating from the eastern slopes of the Truong Son Range, while the Ngan Sau river system is the second largest tributary of Ca river. The main stream of the Ngan Sau river is 100km, the river is narrow and steep with an average width of 30–50m. The river flows through the area with high annual rainfall reaching 2,200–2,400mm [6, 26].

The Ngan Pho River is 70 km long with the average river width of 30–35m, and the river bed is steep and short. The study area is located in the tropical monsoon area, which is hot and humid, with a lot of rain. The soil is mainly suitable for growing food crops and short-term industrial crops. Forests in the river basin are concentrated in two districts of Huong Son and Huong Khe, Ha Tinh province [6]. Ha Tinh province in north central Vietnam is frequently the hardest damaged by floods, in particular in the Ngan Sau, Ngan Pho river basin [24].

3. Data and Research methodology

3.1 Impact of slope length on flood hazard

Slope length is significant topographic criterion influencing flood occurrence. Slope length is the distance between the site of origin of overland flow and the point at which either the slope gradient reduces sufficiently for deposition to start or the runoff water enters a well-defined channel, which may be a drainage network or a manmade channel [27]. Thus, it can be understood as the slope length is equivalent to the measurement between the valley line and the watershed line. This parameter can control the variations along the slope water flow energy by altering the area that receives rain, which in turn, influences how water moves. Slope length is key influence on both the volume and velocity of surface runoff. Longer slopes deliver more runoff to the base of slopes [28]. According to He et al. (2022), slope length was significantly positive correlation with flow velocity and runoff [22]. This can be inferred as the further the slope length, the greater the volume of water, flow speed, and inertia force. This result is in accordance with the study of Begarello and Ferro (2010), Yongmei et al. (2011), and Liu & Singh (2004). Their findings have indicated that the volume of the flow rises with an increasing slope length. A flood occur when large runoff volumes flow rapidly into streams and rivers [29]. Therefore, the closer the distance to the watershed line, the less the flow kinetic energy, the smaller the flow velocity, leading to a reduction in flood hazard [21]. In addition, Kittipongvises et al. (2020) revealed that the higher the runoff, the greater the hazard of flooding [30]. Thus, there will exist a proportional relationship between slope length with runoff and flood hazard.

In addition to affecting the runoff, the slope length also impacts the flow accumulation. Theoretically, the longer the slope, the more runoff will accumulate, gathering speed and gaining its energy [31]. This judgment is the agreement with Balasubramanian's assessments, the slope length increase leads to a greater accumulation of runoff [32]. That means, if slopes are long, when rainfall reaches the soil, the speed and extent to which the flow accumulates on the soil surface strengthen. Furthermore, the proportional relationship between slope length and flow accumulation is also shown in the following formula [33]:

$$LS = \left(\frac{Flow\ Accumulation * Cell\ size}{22.12}\right)^{0.4} * \left(\frac{\sin\theta}{0.0896}\right)^{1.3} \quad (1)$$

where LS is slope length and slope steepness factor, cell size is the pixel size of the DEM, θ is slope steepness in degree.

As such, on a slope, the quantity of water, runoff speed, and the capacity to accumulate water will all gradually rise when water moves from the ridge line to the water concentration areas. Additionally, the time of water concentration affects the water accumulation amount on the same slope.

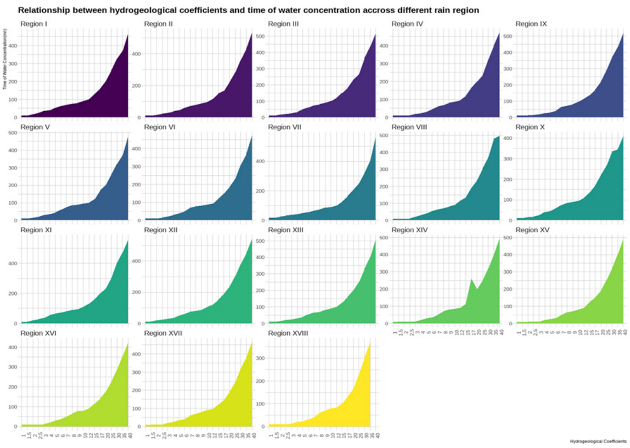

Fig 2. Relationship between hydrogeological coefficients and time of water concentration in the different rain regions of Vietnam [34]

Rys. 2. Zależność współczynników hydrogeologicznych od czasu koncentracji wody w różnych regionach deszczowych Wietnamu [34]

According to Directorate for Roads of Vietnam (2013), the water concentration time on a slope relies on the hydrogeological coefficient of the slope and the rain zone. The larger the geomorphology and hydrological coefficient of the slope, the longer the time of water concentration on the slope. This coefficient is proportional to the slope length and is calculated by the following equation [34]:

$$\Phi_{sd} = \frac{L_{sd}^{0.6}}{m_{sd} J_{sd}^{0.3} (\varphi H_P)^{0.4}} \quad (2)$$

where: Φ_{sd} is the geomorphology and hydrological coefficient of the slope; L is the average slope length of the watershed; J is the slope in percentage; φ is the flood flow coefficient depending the soil type, design daily rainfall and basin area; H_p is the design daily rainfall; msd is parameter of roughness characteristics on the slope relying on the surface condition of the basin slope.

Equation 2 indicates that, the longer the slope length increases, the greater the hydrogeological coefficient of the slope. In addition, the proportional relationship between this coefficient and the time of water concentration in different rain regions is shown on the chart (Figure 2) [34]. Where, the horizontal axis represents Φ_{sd} and the vetical axis shows the water concentration time. The above evidences show that there is a positive correlation between hydrogeological coefficient, time of water concentration and slope length. This demonstrates that the flood hazard increases with the increase of water concentration time and slope length. Therefore, it can be confirmed that slope length is an important parameter affecting flood hazard.

According to Nguyen et al. (2020), there are currently two different types on the concept of slope length including absolute and relative slope length. The former is often determined in length measurement units, making it "absolute" in terms of quantitative sense, while the latter is hierarchized depending on the proportion of the absolute slope length, so it denotes "relative" in terms of quantitative concepts. The concept of absolute slope length is widely used in erosion studies or hydrological and hydraulic calculations, but it is challenging in the hierarchy to establish the flood hazard zone map [21]. Therefore, the present study used the concept of the relative slope length to generate a hierarchical map of slope length, thereby combining with other maps to create a map of flood hazard zoning in the study area.

3.2 AHP method

There are different kinds of flood risk evaluations, which combine qualitative, semi-quantitative, and quantitative techniques [35]. However, the AHP technique is being utilized most frequently to resolve different flood hazard assessment [36]. The AHP is a decision-making methodology created by Thomas Saaty in the 1970s that can evaluate and analyze complex multiple problems [37]. In flood hazard evaluation, AHP can be integrated with various criteria to calculate the flood hazard index. In this paper, to delineate the flood-prone areas, based on the decision makers' consideration, the integration between the AHP algorithm and GIS technology has been applied to determine the weight of factors contributing to flood generation in the study area, including slope length factor. The AHP model involves creating a pair-wise matrix, calculating eigenvalue and weighting coefficients, and enables the calculation of a consistency ratio (CR) to assess the consistency of the priority ranking. The following equation has been used to compute the CR:

$$CR = CI/ RI \quad (3)$$

When CR is the consistency index, RI is the random consistency index that depends on the number of criteria used in the AHP model, and CI is the consistency index calculated as follows:

$$CI = (\lambda_{max} - n)/(n-1) \quad (4)$$

when λ_{max} denotes the largest eigenvalue of the pair-wise comparison matrix; n is the number of parameters.

The AHP result is acceptable if the CR is less than or equal to 0.1. If this value is greater than 0.1, the result is inconsistent with continuing the evaluation and the approach needs to be revised [38].

3.3 Generating flood hazard zone map

Tab. 1. Type data, data sources, and output layers

Tab. 1. Typ i źródła danych, warstwy wyjściowe

Data type	Description	Source	Output layer
Topography map	Scale 1:50 000	Ha Tinh Department of Natural Resources and Environment	DEM, slope map, drainage density map, relative slope length map
Existing Land use map			Land cover map
Soil classification map			Soil map
Rainfall data	In the period from 1961 to 2020	National Centre for Hydro-Meteorological Forecasting	Annual rainfall map
Flood water level in reality of flood events	October 2010, 2013, 2016, 2020	Ha Tinh Department of Natural Resources and Environment	Used to validate the flood hazard zoning map

Tab. 2. Relative weight for thematic layers

Tab. 2. Współczynniki wagowania dla warstw tematycznych

Factors	RF	Sl	DD	S	LU	RSl	Weights	
							Group 1	Group 2
Rainfall (RF)	1	3	5	7	5	5	50.3	45.8
Slope (Sl)	1/3	1	3	5	5	3	27.3	25.3
Drainage Density (DD)	1/5	1/3	1	1	1	1	8.1	7.6
Soil (S)	1/7	1/5	1	1	1	1	6.8	6.6
Land Use (LU)	1/5	1/5	1	1	1	1	7.4	7.1
Relative Slope Length (RSl)	1/5	1/3	1	1	1	1		7.6
CI							0.03	0.02
CR							0.027	0.016

After determining the weights and ratings of each criterion, the following equation has been applied to calculate the flood hazard index. Accordingly, the flood hazard zone map can be developed with help of the raster calculator tool in ArcGIS. This map can show all areas that are at hazard of floods.

$$\text{FHI} = \sum_{i=1}^{n}(W_i * X_i) \quad (5)$$

when X is the weight of factor i; W is the weight value of each parameter

3.4 Datasets

There are two kinds of data to feed into the AHP model including primary data and secondary data. The former was acquired by interviewing people living in the study area and asking for experts' judgment with questionnaires and recorded in the field notes. The latter in this study is defined as data gathered from some institutions.

These data are preliminary information about the study region such as topography map, land use map, population, climate situations, and rainfall. The datasets used in this study are described accordingly in Table 1. Based on this data, the flood hazard zoning map was created to detect flood-prone areas with various hazard levels.

4. Results and Discussion

4.1 Assessment of the importance of factors affecting to flood hazard

In this paper, two groups of influencing factors are used to map the flood hazard zone of the study area. Group 1 includes five criteria that are rainfall, slope, drainage density, soil, and land cover. Group 2, in addition to the five factors in group 1, also includes the relative slope length. The weight of criteria affecting flood hazard was based on their reaction to the occurrence of flood and expert's judgments. A factor with a high weight shows a great impact on flood potential, whereas a variable with a low weight indicates a minor influence. With values ranging from 1 to 9, Saaty's scale of relative importance was used to determine each parameter's weight. These values were allocated relied on previous research, together with experts' judgments. In this study, relative weights are assigned to each thematic layer, as indicated in Table 2.

AHP algorithm allows determining the normalized weight of each factor, as shown in Table 2. The study findings indicate that rainfall have a higher value than others, which means this rainfall is the most important parameter. Slope shows the prospect for high flood hazard, whereas high soil permeability implies low hazard flood. In this study, there are many factors that influence on flood potential listed in increasing order as follows: Soil, land use, drainage density, relative slope length, slope, and rainfall. To assess the appropriateness of the weights assigned to each criterion, the consistency ratio was determined based on the formula (1). The consistency index (CI) value obtained by the calculation is 0.03 (group 1) and 0.02 (group 2). Accordingly, the calculated consistency ratio is 0.027 and 0.016 respectively which are less than 0.1, this means that the weights assigned to the parameters are appropriate for further study.

4.2 Generating the flood hazard zone map

The flood hazard zone map in the study area is produced based on appropriate ratings for thematic layers, their classes on flood potentiality, and their weights. The flood hazard potential zones of the research region were determined by multiplying the influencing factor weight by the cell value of that criterion class and adding the resulting cell values together as following equation:

For Group 1: $\text{FHI} = Rf_w*Rf_r + Sl_w*Sl_r + Dd_w*Dd_r + S_w*S_r + Lu_w*Lu_r \quad (6)$

For Group 2: $\text{FHI} = Rf_w*Rf_r + Sl_w*Sl_r + Dd_w*Dd_r + S_w*S_r + Lu_w*Lu_r + Rsl_w*Rsl_r \quad (7)$

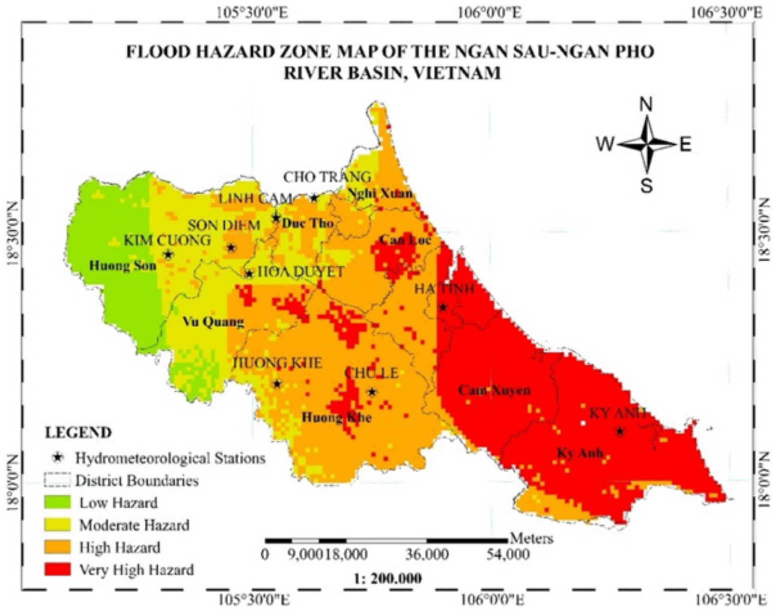

Fig 3. Flood hazard zone map of the study area (created for 5 factors affecting flood formation)

Rys. 3. Mapa stref zagrożenia powodziowego obszaru badań (stworzona dla 5 czynników wpływających na powstawanie powodzi)

where the symbol "w" shows the weight of 1 thematic layer, and the symbol "r" indicates the rating of subclasses in each layer.

The total values calculated by Equation (6) and (7) are classified into an assessment scale of low, moderate, high, and very high. The values of flood hazard zones range from 1.28 to 8.53 (for group 1) and from 1.3 to 8.4 (for group 2). Natural breaks classification of ArcGIS software is used to classify this flood potential zones as Figure 3 and Figure 4.

After opening the command window to perform the analysis of remote sensing image data from GEE, the integration of terrain data DEM, Sentinel 2 remote sensing image with a resolution of 10 × 10 meters, and real-life river cross-section data was performed (Figure 6). Nowadays, Sentinel images can alleviate the effects of clouds, allowing for analysis across more time layers. During the driest periods, the water level in the Ba River remains only in the main channels with the lowest water level. Therefore, the riverbanks and edges of the main channels are without water. Using Sentinel images helps determine the elevation of these areas.

4.3 Validation of flood hazard zone

Verification was performed between the flood hazard zone map and levels of a flood warning at hydrological stations of typical floods. In this study, three flood events were used to verify including floods in October 2010; October 2013; October 2016; and October 2020. In addition, water level data and flood alarm levels at Chu Le, Son Diem, and Hoa Duyet hydrological stations are also used to assess (Table 3). The total accuracy was calculated using the following equation [39]:

The Accuracy (%) = (number of correct sampled/total number of samples) × 100 (8)

In this study, water level data from four flood events in three hydrological stations (that means the total number of samples is 12) were utilized as a point of reference for determining the accuracy of mapping the flood hazard zones. Accuracy is calculated for two cases as follows:

The total accuracy for group 1: (4/12)* 100 = 33%
The total accuracy for group 2: (9/12)* 100 = 75%

Thus, the identification of flood potential areas by six factors affecting flood formation (group 2) has much higher accuracy than the determination based on five factors (group 1). The findings indicated that there is a considerable level of agreement in using factors affecting flood potential of second group to establish the flood hazard zone map with the total accuracy of 75%. This assessment also shows a good connection between flood potential zones in the map and actual flood hazard information. This proves that adding the relative slope length factor to develop the AHP model helps to improve the precision of flood prone area delineation in the study area.

This study is useful in decision making, flood management, and as a guide for future flood monitoring in the study area. Based on the obtained results of this study, it can be concluded that integrated AHP method and GIS technology are very useful, time-efficient, and affordable tools for modeling flood hazard zones, in particular for the data spare areas such as flood prone regions. However, it is necessary to consider carefully before deciding which factors affecting flood generation to include in the calculation model. This selection depends not only on the physical geography characteristics of the study area, but also on the availability of data. This is not simple, especially for the ever-changing subject of flood. In addition, the number of criteria also needs to be considered, just choosing from 5 to 9 factors is enough. Moreover, in order to improve accuracy and increase the level of agreement between predicted results and actual happens, the data used to develop the model should be real-time data or data closest to prediction time.

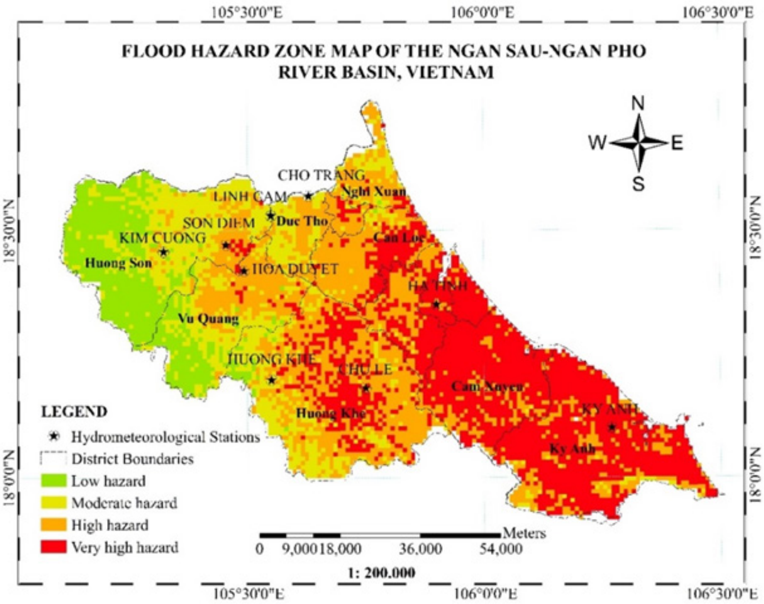

Fig. 4. Flood hazard zone map of the study area (created for 6 factors affecting flood formation)

Rys. 4. Mapa stref zagrożenia powodziowego obszaru badań (stworzona dla 6 czynników wpływających na powstawanie powodzi)

Tab. 3. Validation of flood hazard zone using data of flood evens (Data Source: Ha Tinh Committee for Flood and Storm Control)

Tab. 3. Walidacja strefy zagrożenia powodziowego na podstawie danych o zjawiskach powodziowych

River	**Hydrologic-al stations**	**Flood even**	**Actual description**			**Expected description**			
			Water level (m)	Flood danger level	Hazard level	Group 1	Agreement	Group 2	Agreement
Ngan Sau	Chu Le	16-18 October, 2010	16.56	Above warning level 3 (3.06 m)	Very high	High	Disagree	Very high	**Agree**
	Hoa Duyet		12.37	Above warning level 3 (1.87 m)	Very high	Very high	**Agree**	Very high	**Agree**
Ngan Pho	Sơn Diem		13.0	Above warning level 3 (0.78 m)	Very high	High	Disagree	Very high	**Agree**
Ngan Sau	Chu Le	15, 16 October, 2013	14.42	Above warning level 3 (0.92 m)	Very high	High	Disagree	Very high	**Agree**
	Hoa Duyet		11.26	Above warning level 3 (0.76 m)	Very high	Very high	**Agree**	Very high	**Agree**
Ngan Pho	Sơn Diem		14.62	Above warning level 3 (1.62 m)	Very high	High	Disagree	Very high	**Agree**
Ngan Sau	Chu Le	15, 16 October, 2016	15.64	Above warning level 3 (2.14 m)	Very high	High	Disagree	Very high	**Agree**
	Hoa Duyet		10.91	Above warning level 3 (0.41 m)	Very high	Very high	**Agree**	Very high	**Agree**
Ngan Pho	Sơn Diem		12.8	Under warning level 3 (0.2 m)	High	High	**Agree**	Very high	Disagree
Ngan Sau	Chu Le	19 October, 2020	14.5	Above warning level 3 (0.5 m)	Very high	High	Disagree	Very high	**Agree**
	Hoa Duyet		9.41	Above warning level 2 (0.41 m)	High	Very high	Disagree	Very high	Disagree
Ngan Pho	Sơn Diem		10.5	Above warning level 1 (0.5 m)	Moderate	High	Disagree	Very high	Disagree

5. Conclusions

In the present study, the AHP approach along with GIS technology was used to determine the flood prone zones of Ngan Sau, Ngan Pho river basin, based on influential variables in two groups. This procedure successfully achieves the satisfactory findings with regard to the identification of flood potential areas. The AHP analysis reveals that meteorological factor such as rainfall, physical criteria such as slope, drainage density, relative slope length have greater impact on flood formation. Two flood hazard zone maps of the study areas were generated using two data groups. The result maps were verified based on flood warning levels of four historical flood evens. The results of predicting flood hazard areas that take into account this factor are much more accurate and reliable than those made without that criterion. Therefore, it can be asserted that it is necessary to include the relative slope length to delineate the flood potential zones in Ngan Sau,

Ngan Pho river basin. In addition, since data preparation is not too complicated, this parameter can also be considered for use in other geographical areas to identify flood prone zones.

Acknowledgements

This study was completed based on the results of the research project: Research on evaluating changes of slope length to flood risk zoning (case study: Ngan Sau and Ngan Pho river basins, Ha Tinh province), Hanoi University of Natural Resources and Environment. Topic code: 13.01.23.E.01.

Thanks to two anonymous reviewers and editorial comments for their valuable comments in the earlier version, which helped us to improve the manuscript's quality

Conflicts of Interest

The authors declare no conflict of interest.

Ethical statement

The authors state that the research was conducted according to ethical standards.

Funding body

This research is no funding.

Literatura – References

1. Yodying, A., Seejata, K., Chatsudarat, S., Chidburee, P., Mahavik, N., Kongmuang, C., and Tantanee, S. (2019) Flood hazard assessment using fuzzy analytic hierarchy process: A case study of Bang Rakam model in Thailand. In: Proceedings of the 40th Asian Conference on Remote Sensing, Daejeon Convention Center (DCC), Daejeon, KR, pp. 14-18.
2. Sriariyawat, A., Kimmany, B., Miyamoto, M., Kakinuma, D., Pc, S., and Visessri, S. (2022). An Approach to Flood Hazard Mapping for the Chao Phraya River Basin Using Rainfall-Runoff-Inundation Model. Journal of Disaster Research. 17(6), p. 864-876.
3. Alarifi, S.S., Abdelkareem, M., Abdalla, F., and Alotaibi, M. (2022). Flash Flood Hazard Mapping Using Remote Sensing and GIS Techniques in Southwestern Saudi Arabia. Sustainability. 14(21), p. 14145.
4. Singha, C., Swain, K.C., Meliho, M., Abdo, H.G., Almohamad, H., and Al-Mutiry, M. (2022). Spatial Analysis of Flood Hazard Zoning Map Using Novel Hybrid Machine Learning Technique in Assam, India. Remote Sensing. 14(24), p. 6229.
5. Ba, D.N., Quynh, N.N., Thi, L.P., and Tuyet, M.D. (2021). Evaluation and validation of flood hazard zoning using Analytical Hierarchy Process and GIS: A case study of Lam River basin (Vietnam). Вестник Санкт-Петербургского университета. Науки о Земле. 66(4), p. 831-851.
6. Minh, D.T. (2021). Flood hazard zoning in Ngan Sau, Ngan Pho river basin, Ha Tinh province using GIS and analytical hierarchical process HNUE JOURNAL OF SCIENCE. 66(1), p. 198-212.
7. Dung, N.B. and Minh, D.T. (2021). Assessment of flood influence criteria in the lam river basin using a combined Delphi-AHP method. Sustainable development of mountain territories. 13(3), p. 387-396.
8. Dang, T.M. and Nguyen, L.T.D. (2021). Integration of Delphi technique and analytical hierarchy process method in assessment the groundwater potential influence criteria: a case study of the Ba River Basin. Inżynieria Mineralna. 38(2).
9. Kumar, A. and Pant, S. (2022). Analytical hierarchy process for sustainable agriculture: An overview. MethodsX. 10.
10. Dung, N.B., Minh, D.T., An, B.N., and Nga, N.Q. (2021). Assessment of vulnerability In agricultural land in flood prone Areas and application of mobile smart Phone in providing flood hazard Information in lam river Basin (Vietnam). Sustainable development of mountain territories. 2(48), p. 254-265.
11. Teshnizi, E.S., Golian, M., Sadeghi, S., and Rastegarnia, A. (2022). Application of analytical hierarchy process (AHP) in landslide susceptibility mapping for Qazvin province, N Iran. Computers in Earth and Environmental Sciences, p. 55-95.
12. Minh D.T, Dung N.B. (2023). GIS-based multi-criteria approach for drought hazard modeling in the Ba river basin, Vietnam. Environmental Earth Sciences, 30(83):30.
13. Dung, N.B., Long, N.Q., An, D.T., and Minh, D.T. (2022). Multi-geospatial flood hazard modelling for a large and complex river basin with data sparsity: a case study of the Lam River Basin, Vietnam. Earth Systems and Environment. 6(3), p. 715-731.

14. Dung, N.B., Long, N.Q., Goyal, R., An, D.T., and Minh, D.T. (2022). The role of factors affecting flood hazard zoning using analytical hierarchy process: A review. Earth Systems and Environment. 6(3), p. 697-713.

15. Fu, X., Zhang, L., and Wang, X. (2016). The effect of slope length on sediment yield by rainfall impact under different land use types. Water resources. 43(3), p. 478-485.

16. Liu, B., Nearing, M., Shi, P., and Jia, Z. (2000). Slope length effects on soil loss for steep slopes. Soil Science Society of America Journal. 64(5), p. 1759-1763.

17. Qiu, H., Cui, P., Regmi, A.D., Hu, S., Wang, X., and Zhang, Y. (2018). The effects of slope length and slope gradient on the size distributions of loess slides: Field observations and simulations. Geomorphology. 300, p. 69-76.

18. Fu, X., Zhang, L., and Wang, Y. (2019). Effect of slope length and rainfall intensity on runoff and erosion conversion from laboratory to field. Water Resources. 46(4), p. 530-541.

19. Huang, K., Liu, R.-L., Qin, L., Song, T., Liu, Z.-X., and Li, R. (2021). Effects of slope length on soil erosion of Karst slope under different rainfall conditions. Ying Yong Sheng tai xue bao= The Journal of Applied Ecology. 32(1), p. 271-280.

20. Kinnell, P. (2000). The effect of slope length on sediment concentrations associated with side-slope erosion. Soil Science Society of America Journal. 64(3), p. 1004-1008.

21. Nguyen, B.D., Minh, D.T., Ahmad, A., and Nguyen, Q.L. (2020). The role of relative slope length in flood hazard mapping using AHP and GIS (case study: Lam River Basin, Vietnam). Geography, Environment, Sustainability. 13(2), p. 115-123.

22. He, Z., Xiao, P., Yu, X., Hao, S., Jia, G., and Yang, C. (2022). A Field Study for the Effects of Grass Cover, Rainfall Intensity and Slope Length on Soil Erosion in the Loess Plateau, China. Water. 14(14), p. 2142.

23. Verrina, G.P., Anugerah, D.D., and Haki, H. (2013). Analisa runoff pada Sub DAS Lematang hulu. Jurnal Teknik Sipil Dan Lingkungan. 1(1).

24. Tran, H.T. and Nguyen, T.T. (2020). A GIS-based spatial multi-criteria approach for flash flood risk assessment in the Ngan Sau-Ngan Pho mountainous river basin, North Central of Vietnam. Environment and Natural Resources Journal. 18(2), p. 110-123.

25. Dang Tuyet Minh. (2021). Flood hazard zoning in Ngan Sau, Ngan Pho river basin, Ha Tinh province using GIS and analytical hierarchical process. Journal of Science. 1.

26. Thanh, N.T., Huy, N.A., Huong, P.T.T., and Trang, T.T.T. (2023). Flash Flood Hazard Mapping Using Landsat-8 Imagery, AHP, And GIS In The Ngan Sau And Ngan Pho River Basins, North-Central Vietnam. Geography Environment Sustainability. 16(2).

27. Smith, D.D. and Wischmeier, W.H. (1957). Factors affecting sheet and rill erosion. Eos, Transactions American Geophysical Union. 38(6), p. 889-896.

28. Martin, O.M., Anthony, G.B., and Robert, M.S. (2011). Maryland Standards and Specifications for Soil Erosion and Sediment Control. Baltimore.

29. Konrad, C.P. (2003). Effects of urban development on floods.

30. Kittipongvises, S., Phetrak, A., Rattanapun, P., Brundiers, K., Buizer, J.L., and Melnick, R. (2020). AHP-GIS analysis for flood hazard assessment of the communities nearby the world heritage site on Ayutthaya Island, Thailand. International Journal of Disaster Risk Reduction. 48.

31. Roose, E. (1996). Land husbandry: components and strategy. Vol. 70: FAO Rome.

32. Balasubramanian, A. (2017). Soil erosion–causes and effects. Centre for Advanced Studies in Earth Science, University of Mysore, Mysore. 12(12).

33. Negese, A., Fekadu, E., and Getnet, H. (2021). Potential soil loss estimation and erosion-prone area prioritization using RUSLE, GIS, and Remote Sensing in Chereti Watershed, Northeastern Ethiopia. Air, Soil and Water Research. 14, p. 1-17.

34. Directorate for Roads of Vietnam, T. (2013). Calculating of flood flow characteristics (in Vietnamese with English summary).

35. Van Westen, C., Alkema, D., Damen, M., Kerle, N., and Kingma, N. (2011). Multi-hazard risk assessment: distance education course guide book. United Nations University-ITC School on Disaster Geo-information Management (UNU-ITC DGIM).

36. De Brito, M.M. and Evers, M. (2016). Multi-criteria decision-making for flood risk management: a survey of the current state of the art. Natural Hazards and Earth System Sciences. 16(4), p. 1019-1033.

37. Saaty, R.W. (1987). The analytic hierarchy process—what it is and how it is used. Mathematical modelling. 9(3-5), p. 161-176.

38. Mitra, R., Saha, P., and Das, J. (2022). Assessment of the performance of GIS-based analytical hierarchical process (AHP) approach for flood modelling in Uttar Dinajpur district of West Bengal, India. Geomatics, Natural Hazards and Risk. 13(1), p. 2183-2226.

39. Jensen, J.R. (1996). Introductory digital image processing: a remote sensing perspective. Prentice-Hall Inc.

Znaczenie danych o względnej długości zboczy w strefach zagrożenia powodziowego: studium przypadku Ngan Sau, dorzecze rzeki Ngan Pho, Wietnam

Modelowanie powodzi dostarcza przydatnych informacji, które pomagają zarządzać zagrożeniem powodziowym i łagodzić skutki powodzi w lokalizacjach narażonych na powodzie. W ramach niniejszych badań opracowano mapy zagrożenia powodziowego dla dorzeczy rzek Ngan Sau i Ngan Pho przy użyciu technologii GIS i metody Analytical Hierarchy Process (AHP). Dokładność wyników symulacji powodzi zależy od kryteriów powodujących powódź. Celem pracy była ocena roli względnej długości zbocza w identyfikacji i wyznaczaniu zagrożenia powodziowego. Do określenia odpowiednich wag w AHP wykorzystano sześć czynników geograficznych i metrologicznych — opady deszczu, nachylenie, gleba, użytkowanie gruntów, gęstość drenażu i względna długość zbocza. W procesie obliczania modelu czynniki te dzielone są na dwie grupy: grupa 2 obejmuje wszystkie sześć parametrów, natomiast grupa 1 obejmuje pięć kryteriów z wyłączeniem kryterium względnej długości nachylenia. W oparciu o stany ostrzeżeń powodziowych na stacjach hydrologicznych na obszarze badań podczas powodzi, które miały miejsce w przeszłości, zweryfikowano skutki wyznaczania stref zagrożenia powodziowego. Uzyskane wyniki wykazały, że mapy opracowane z grupy kryteriów uwzględniających względną długość nachylenia są dokładniejsze niż mapy wygenerowane na podstawie pozostałych pięciu czynników. Wyniki artykułu mogą posłużyć jako punkt odniesienia przy wyborze kryteriów tworzenia modeli stref zagrożenia powodziowego z wykorzystaniem kombinacji technologii AHP i GIS.

Słowa kluczowe: *proces hierarchii analitycznej, AHP, zagrożenie powodziowe, względna długość nachylenia, Ngan Sau, dorzecze rzeki Ngan Pho*