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WEIGHTS OF FACTORS CONTRIBUTING TO FLOOD FORMATION IN THE LAM RIVER BASIN, VIETNAM

越南兰河盆地洪水形成的影响因素

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Abstract

There are many factors that influence the formation and development of floods, such as rainfall, soil, slope, land cover, drainage, and density. Therefore, a quantitative assessment of their importance is necessary, especially in the determination of flood risk zones, using the Analytic Hierarchy Process algorithm and Geographic Information System. In comparison with other methodologies, an obvious advantage of Analytic Hierarchy Process is the ability to solve multi-variable qualitative and quantitative problems with precise and trustworthy results. This paper presents the application of the Analytic Hierarchy Process algorithm in analyzing and evaluating the level at which various criteria affect flood risk in the Lam River basin. Some of the flood-causative factors considered in this paper are annual rainfall, soil, slope, land cover, drainage density, and relative slope length. These factors were chosen based on the physical conditions of the study area. The research results are the weight of different criteria. The higher the weight, the higher the effect of that criterion on flood risk. The computed weights show that annual rainfall and slope are the factors that contribute the most to flooding, based on decision-makers' judgement. The results of this article can be used to construct a flood risk zoning map and flood susceptibility map for flood warnings in the Lam River basin, using the Analytic Hierarchy Process method and Geographic Information System technology. New research shows that Analytic Hierarchy Process can be trustworthy when assessing the level of influence of the different factors on determining flood-prone areas in the Lam River basin, as well as other basins.

Keywords: Analytic Hierarchy Process Algorithm, Weight of Factor, Flood Risk, Flood Formation, Lam River Basin

摘要 有很多因素会影响洪水的形成和发展，例如降雨，土壤，坡度，土地覆盖，排水和密度。因此，有必要对它们的重要性进行定量评估，尤其是在使用洪水等级分析法和地理信息系统确定洪水风险区时。与其他方法相比，层次分析法的一个明显优势是能够解决多变量定性和定量问题，并且结果准确可靠。本文介绍了层次分析算法在分析和评估各种标准影响林河流域洪水风险的水平上的应用。本文考虑的一些洪灾成因包括年降雨量，土壤，坡度，土地覆盖，排水密度和相对坡长。这些因素是根据研究区域的物理条件选择的。研究结果是不同标准的权重。权重越高，该标准对洪水风险的影响就越大。根据决策者的判断，计算得出的权重表明，年降雨量和坡度是造成洪灾的最大因素。运用层次分析法和地理信息系统技术，可以将本文的结果用于构建林河流域洪水预警的洪水风险区划图和洪水敏感性图。最新研究表明，在评估不同因素对确定兰姆河流域以及其他流域易发洪水地区的影响程度时，层次分析法是值得信赖的。

关键词: 层次分析算法，因子权重，洪水风险，洪水形成，林河流域

I. INTRODUCTION

Factors contributing to the formation of flood risk include physical geography, socioeconomics, and infrastructure. However, it is necessary to determine which factors have the greatest impact on flood risk in the study area and how to quantify these factors [1]. A widely used Multi-Criteria Evaluation (MCE) approach is the Analytic Hierarchy Process (AHP), developed by Saaty [2]. The AHP method has numerous advantages compared to other multi-objective decision-making methods. First, many methods have difficulty in determining the importance of each criterion, while AHP is a well-known method of determining these weights with high accuracy [3], [4]. Therefore, AHP can be combined with other methods to take advantage of the strengths of each in solving problems.

In addition, AHP can check consistency in decision-makers' judgment so it is possible to identify and improve the accuracy of the assessment. Furthermore, the process of calculating becomes easier, even for a large number of criteria, because it is possible to perform calculations in Excel or using online software utilizing a Common Gateway Interface (CGI).

If the input data is the size and the elements of the matrix, as well as the paired matrix, the result is a weight and a consistency index. Another method that has been often used for calculating is integrating the eigenvectors AHP method into ArcGIS software. The successful construction of the AHP calculation tool on ArcGIS has provided the ability to avoid cumulative errors through many steps and to decrease the calculation time, as well as limiting the error when calculating by hand; hence, the idea of creating a utility tool that is easy to use to support decision making. The use of the AHP algorithm to calculate the weight of each criterion is the main stage in the process of establishing a flood-risk zoning map. This method is suitable for analyzing a large number of different factors affecting the flood risk zone; moreover, it also helps when analyzing complex decision-making issues with multiple criteria based on gradual reduction of values by comparing each pair of parameters according to all criteria [5]. The paper presents the results of prioritizing the factors affecting the flood risk in the Lam river basin using the AHP algorithm.

In recent years, this method has received much attention from domestic and international scientists when zoning flood hazard. In Vietnam, two case studies based on this method were conducted in the Huong river basin [6] and Vu Gia river basin [1]. Both studies selected typical causes of floods, such as rainfall, slope, drainage density, and soil types, to be parameters for calculating the model. In the whole world, there have been many studies in different geographical regions using this method in flood risk zoning [1], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21]. The selection of criteria for implementing the model depends on the geographical area and the ability to find relevant documents.

II. PRACTICAL BASES USE AHP IN ZONING FLOOD RISK IN THE LAM RIVER BASIN

A. Research Area

The Lam river basin (Figure 1) is located at the geographical coordinates from $103^0 14'$ to $106^0 10'$ E longitude and from $17^0 50'$ to $20^0 50'$ N latitude, extending about 350 km in the direction of Northwest-Southeast; the North is adjacent to the Ma River system, the West borders the Mekong river system, the South borders the

Gianh river basin, and the East borders the Tonkin Gulf. The topography of the Lam river basin consists of three regions: high mountains, midlands and plains; the main slope direction is in the Northwest-Southeast direction, from the Truong Son range with a height of over 2000m with steep, dangerous terrain [22]. The delta only accounts for 14% ÷ 19% of the total area; the length of the river is short so the slope of the rivers is very high. The midland and mountainous areas are narrow transition areas, and the terrain is steep and highly dissected, so, when there is heavy rain, flood concentration is rapid, leading to flood water rushing downstream quickly and violently. Besides, the ground contains many types of soils that are less permeable to water, thus increasing the water concentration time [22].

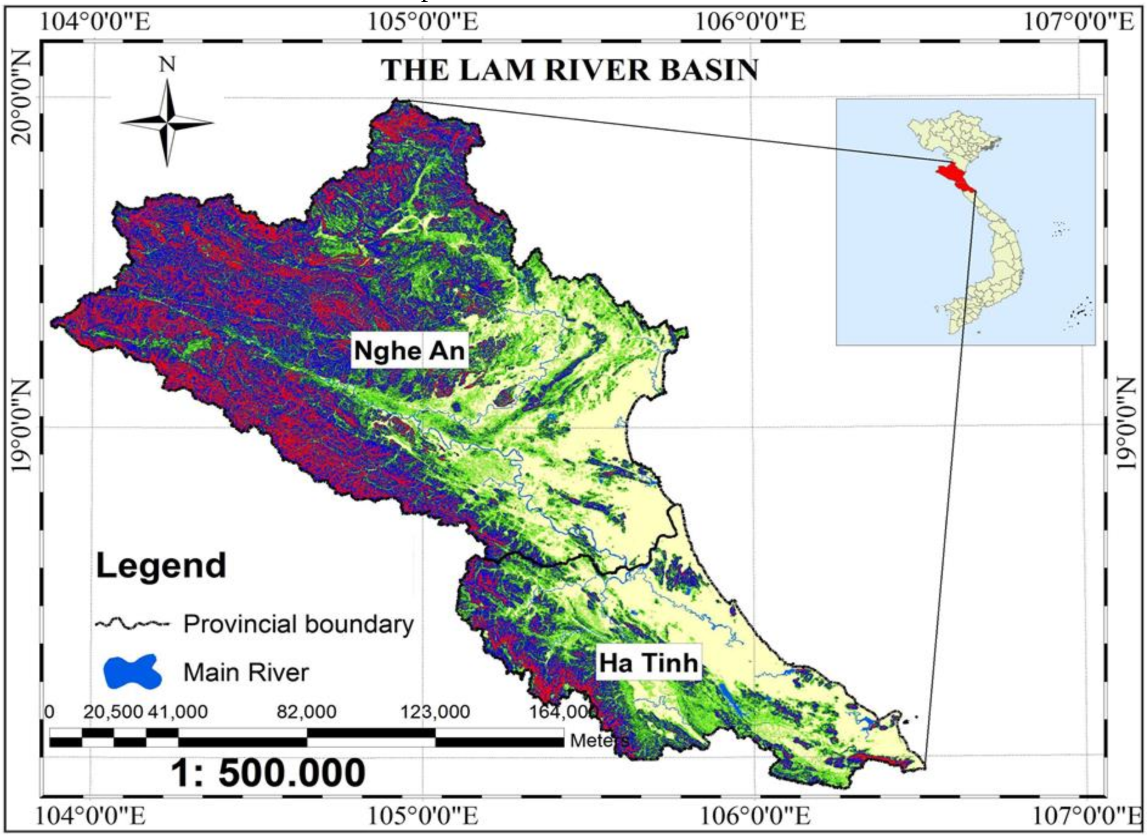

Figure 1. Lam river basin map (Vietnamese territory)

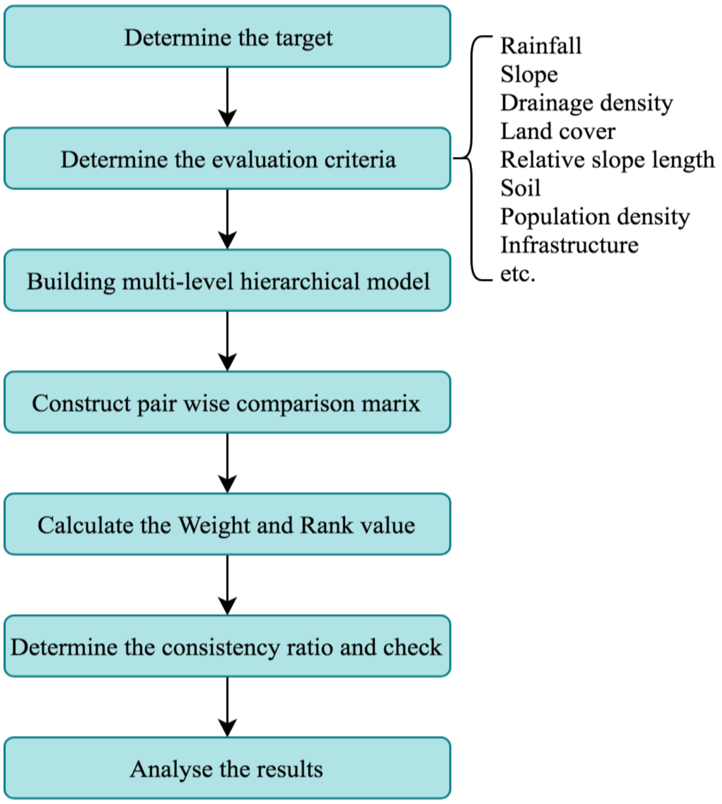

Figure 2. Block diagram of steps of AHP in zoning flood risk

Thus, flood in the Lam river basin is mainly due to heavy rain over a long time in a large region. In addition to topographic conditions, rainfall, slope, soil, vegetation, etc. the infrastructure conditions and adverse impacts of human socio-economic activities are also important factors, contributing to increase flood in the river basin. With a large number and diversity of parameters affecting flood risk, this paper uses the AHP algorithm to assess the level of flood impacts of the affected criteria. The block diagram of the AHP processing stages applied in the flood risk zone is shown in Figure 2. Below is a detailed presentation of each step in the implementation of the Analytic Hierarchy Process (AHP).

B. Determine the Target

This is the first step when implementing the AHP method in flood hazard zoning, the parameters will not be the same for different study areas because of the variety of factors affecting flood.

In fact, the influencing factors are determined through the cause of the flood. It is necessary to study the causes, characteristics, formation mechanisms, physical geography and socio-economic conditions in order to identify the main factors that directly affect floods. The main causes of floods can be divided into groups such as physical geography, socio-economic and infrastructure.

Group 1: physical geography, including slope, cover land, drainage density, rainfall, soil, depth of groundwater, relative slope length, etc.

Group 2: socio-economy including land use, population distribution, etc.

Group 3: infrastructure, including flood prevention works, road system, etc.

Many studies on floods, flash floods, mudflow, etc. show that rainfall is always the factor affecting flood risk the most [7], [8], [15], [17], [20], [21], [24]. In addition to rainfall, slope, elevation, soil, drainage density, land use, etc. are also mentioned by many scientists in zoning flood risk [7], [8], [9], [10], [12], [13], [15], [17], [21], [23]. Based on the physical geography, socio-economic features of the Lam River basin, referred to the research, the factors affecting the flood risk zoning selected for this study are in the group of physical geography including: rainfall, slope, drainage density, soil, cover land, relative slope length. These are factors that are less obstructing when collecting data and not very difficult when calculating the AHP method.

C. Building Multi-Level Hierarchical Model

After identifying the factors that affect flood hazard, building a hierarchical structure to arrange the elements selected according to different levels to be the basis for the pairwise comparision process. Normally, the multi-stage hierarchical model for zoning flood hazard should be 4 levels as shown in Figure 3, in which level 1 represents the target of flood risk zone, level 2 represents the main criteria including: physical geography, socio-economic and infrastructure, level 3 represents the component criteria to detail the main criteria such as topography, rainfall, land use, etc. and the final level showing the risk value.

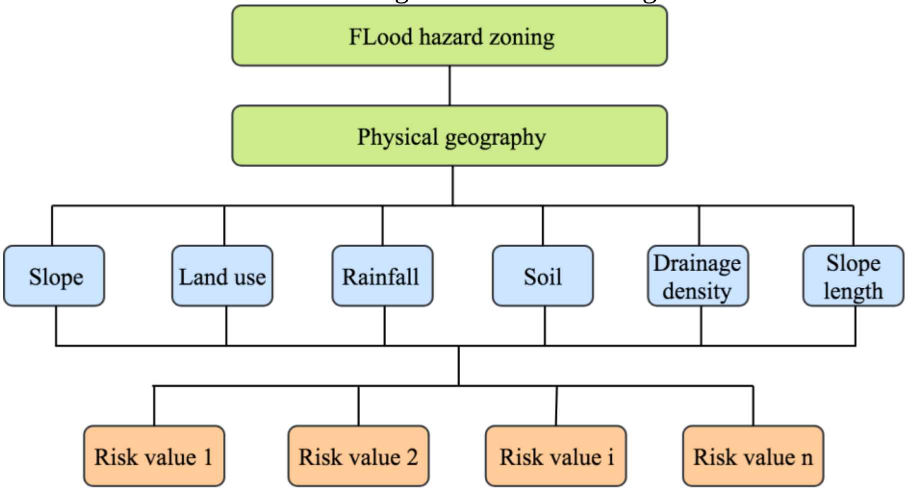

Figure 3. Multi-stage hierarchical structure in zoning flood risk

In this paper, since the evaluation criteria selected are phisical geography factors so the main criteria of level 2 in the multi-stage hierarchy model will be physical geography elements. After the hierarchy of criteria is established, the next task is to make a pairwise comparison of those criteria and build a weight matrix.

D. Establishment of Pairwise Comparison Matrix

The flood affected elements have different roles and importance, so it is necessary to evaluate them properly and select the most important criteria. Flood formation is closely related to rainfall, climatic conditions, topographical features, drainage conditions, infrastructure, population density as well as human activities, etc. Research areas with different physical geography, socio-economic features can select factors that directly affect different flood risks with uneven levels of influence. In addition, with the same impact criteria in different geographical areas, the degree of impact may also vary.

The coefficients of the comparison matrix are calculated from the pairwise comparisons of influencing criteria, index values through the survey questionnaire consulted by experts and local authorities representing the fields such as environment, water resources, sociology, geomatics, hydrology, etc.

E. Calculate the Weight of Each Criterion and Consistent Index

To calculate the weights of affected factors, it is possible to apply an eigenvectors method or matrix normalization method. The greater the weight of the factor, the more likely it will affect the risk of flood occurrence. Standardized matrix and weight set of factors can be calculated and included in the table. The accuracy of the assessment and the prioritized factors will need to be checked for consistency by calculating a consistent ratio.

F. Check the Consistency Ratio

To assess the validity of the important level of factors, Saaty, T.L. used consistent ratio (CR) of data. This ratio compares the consistency level with the objectivity (randomness) of the data. The AHP algorithm in the flood zoning is accurate and consistent if the value of CR is less than or equal to 0.1 [2], [5]. On the contrary, performing the steps as the algorithm diagram shown in Figure 4.

III. Results and Discussion

Flood-influencing factors play an importance role, so it is necessary to assess quantitatively the these elemants. Assessement can be done through determining weight or based on the analysis results of factors or the knowledge of experts. The author has asked the experts on Hydrology, Water Resources, Geology, Land, Geomatic, Environment and Geography at universities, specialized agencies on Hydrometeorology, Research Instituteson related fields with online questionnaires assessing the impact of the criteria on flood risk in Vietnamese and English. The content of this form focuses on two issues:

- Ranking the priority of 6 factors affecting flood hazard including: slope, soil, land cover, rainfall, drainage density and relative slope length.

- Evaluation and scoring for each pair of factors according to the Saaty rating scale.

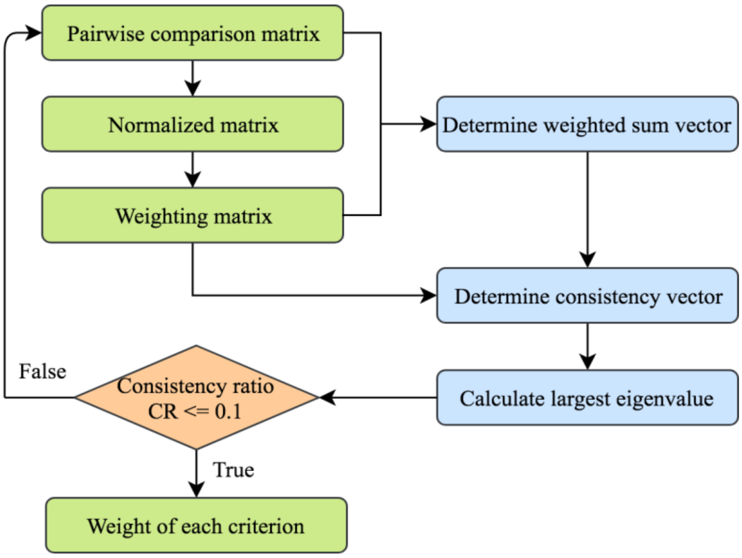

Figure 4. Algorithm diagram to calculate the weight of each criterion according to the matrix normalization method

Table 1.
The summarized results the priority of the factors affecting flood

No.	Pairwise comparison factors	Average mark
1	Rainfall and soil	7
2	Rainfall and slope	3
3	Rainfall and land cover	5
4	Rainfall and drainage density	5
5	Rainfall and relative slope length	5
6	Soil and slope	-5
7	Soil and land cover	1
8	Soil and drainage density	1
9	Soil and relative slope length	1
10	Slope and land cover	5
11	Slope and drainage density	3
12	Slope and relative slope length	3
13	Land cover and drainage density	1
14	Land cover and relative slope length	1
15	Drainage density and relative slope length	1

From the results in Table 1, pairwise comparison matrix is built to calculate the appropirate weight, reflecting the role of each factor that affect the flood hazard based on the point above by using Saaty's AHP algorithm.

In order to maintain the objectivity of the opinions, the author consulted with 60 experts of hydrology, water resources, geology, soil, environment, and geomatics both domestic and foreign. Based on the answers of experts and scientists, the paper collects the results and calculates preferred factors in each pair by taking mean of each factors (Table 1). In this table, the minus (-) shows that the former factor is less important (have less effect) than the latter facter in the comparison factors. From the results in Table 1, pairwise comparison matrix (Table 2) is built to calculate the appropirate weight, reflecting the role of each factor that affect the flood hazard based on the point above by using Saaty's AHP algorithm.

Table 2.
Pairwise comparison matrix of factors affecting flood hazard

Criteria	Rainfall	Soil	Slope	Land cover	Drainage density	Relative slope length
Rainfall	1	7	3	5	5	5
Soil	1/7	1	1/5	1	1	1
Slope	1/3	5	1	5	3	3
Land cover	1/5	1	1/5	1	1	1
Drainage density	1/5	1	1/3	1	1	1
Relative slope length	1/5	1	1/3	1	1	1
Sum of a column	2.076	16.000	5.067	14.000	12.000	12.000

This research applies the matrix normalization method to calculate the weight of factors affecting flood. The weights are determined by calculating the ratio of elements by columns and by rows. These values show what percentage each element accounts for in the total value of the elements and are calculated by dividing values of elements in the comparison matrix by the sum of the corresponding column [2], [24]. The standardization matrix is used to determine the weights of elements as in Table 3, from there knowing the importance of each factors affecting flood.

Table 3.
Standardization matrix

Factors	Rainfall	Soil	Slope	Land cover	Drainage density	Relative slope length	Sum of a row	Weight
Rainfall	0.482	0.437	0.592	0.358	0.417	0.417	2.892	0.450
Soil	0.069	0.062	0.039	0.071	0.083	0.083	0.414	0.068
Slope	0.161	0.312	0.197	0.358	0.251	0.251	0.966	0.255
Land cover	0.096	0.062	0.039	0.071	0.083	0.083	0.576	0.073
Drainage density	0.096	0.062	0.065	0.071	0.083	0.083	0.576	0.077
Relative slope langth	0.096	0.062	0.065	0.071	0.083	0.083	0.576	0.077
Sum of a column	1.000	1.000	1.000	1.000	1.000	1.000	6.000	

The calculation results in Table 3 show that: rainfall has the larges effect on the flood hazard (45%), next is slope (25.5%), relative slope length (7.7%), drainage density (7.7%), land cover (7.3%) and the last oneis soil (6.8%). The parameters of AHP are shown in Table 4. With the result of consistent ratio CR = 0.03 < 0.1, so the above comparison matrix is consistent i.e these weights (Table 3) are accepted.

Table 4.
Parameters of AHP

Parameters	Value
Eigen value (λ_{max})	6.18
The number of impact factors (n)	6
Consistency index (CI)	0.04
Random consistency index (RI)	1.24
Consistency ratio (CR)	0.03

Two factors that have the highest effect on the flood hazard in this research are rainfall and slope. These are the two factors that were mentioned in the reseach of Kieu Tran Duy [22] when zoning flood hazard in Lam river basin using the main factor analysis method. In this study, calculated weights (highest effect) of rainfall and slope are 40% and 25% respective and the result of the paper is almost similarto the weight of rainfall of 45% and the weight of slope of 25.5%. Therefore, besides testing the result of the calculation by the consistency ratio CR (smaller than or equal 0.1), comparing the weight of 2 factors rainfall and slope in the research of Kieu Tran Duy [22] with calculation results of the research shows that AHP can be reliable when evaluating the level of effect of factors to zone flood hazard on the Lam river basin as well as other basins.

IV. Conclusion

In order to solve the problem with many variables, many factors, and to arrange the solutions by priorities, AHP is an effective method being used in evaluating and selecting the factors to zone flood hazard. AHP algorithm shows that the level of effect of factors to the flood hazard on the Lam river basin from highest to lowest are: rainfall, slope, relative slope length, drainage density, land cover, and soil. This is an important finding that can be used to build a flood hazard zoning map improving the forecasting of flood on the Lam river basin. The accuracy of the analysis, evaluation will be dependent on content, comprehensiveness, and features of the survey questionnaire as well as the knowledge of the experts about the research field. Therefore, in order to the weight calculation in AHP achieves the best result, it is recommended to select only a few criteria with a clear effect on the flood and highly quantitative in the process of collecting expert opinions. The subsequent study will include the integration of these weights into Geographic Information System (GIS) environment for spatial flood susceptibility mapping, flood hazard zoning map.

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