Transport and Communications Science Journal, Vol. 74, Issue 1 (01/2023), 1-9

Transport and Communications Science Journal

WEIGHT EVALUATION OF FACTORS INFLUENCING ROAD FLOOD RISK IN MEKONG RIVER DELTA

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ARTICLE INFO

TYPE: Research Article
Received: 30/08/2022
Revised: 08/11/2022
Accepted: 28/11/2022
Published online: 15/01//2023
https://doi.org/10.47869/tcsj.74.1.1
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Abstract. The Mekong River Delta is one of the most vulnerable areas in the world. Because of climate change, the risk of road flooding in the Mekong River Delta is increasing. Road flood disaster is considered as a series of damage processes affecting a road under the effect of different factors such as natural and social factors. Thus, index weight evaluation is a critical part in multi-index evaluation as well as road flood risk management. Some main flood-causative factors considered in this paper are road characteristics, climatic factors, hydrological characteristics, geology environmental factors and social factors. The significant criteria of road flood vulnerability are identified. The weight of different criteria was determined using the subjective method based on the Analytic Hierarchy Process (AHP). The obtained weights can be used for the flood risk evaluation and classification, providing valuable information for decision-making process in the road flood management to prevent and decrease the losses of roads during natural disaster like flooding.

Keywords: flood risk, weight evaluation, subjective method, AHP, objective method, Mekong River Delta.

1. INTRODUCTION

According to the 2019 INFORM Risk Index, Vietnam has extremely high exposure to flooding with the maximum score of 10 and ranked 1st with Bangladesh [1, 2]. Vietnam also ranks fourth among countries with the highest proportion of the population exposed to river flood risk worldwide [3]. Vietnam is exposed to many different types of floods such as fluvial floods (river floods), flash floods, pluvial floods, coastal floods, typhoons and storm surges [4].

Table 1. Flood in Vietnam from 1900 to 2020 [1].

Flood type	Events count	Total deaths	Total affected	Total damage (.000 USD)
Riverine flood	52	3.644	25.637.158	2.896.407
Coastal flood	6	804	4.533.316	749.000
Flash flood	13	481	912.607	516.700
Others	16	1.012	2.011.287	160.055

Especially in the South of Vietnam, the Mekong River Delta is seriously affected by the fluvial flood, which is driven by the flood discharge from the upstream, local heavy rainfall (driven by monsoon or typhoons), high tides in the East Sea and West Sea and storm surges [5]. Floods within the Mekong River Delta are a frequently occurring natural process, an annual event that causes negative direct and indirect impacts during and after extreme events. There were 12 damaging floods in the Mekong River Delta in the period 1960-2020. The annual flooding season occurs in the Mekong River Delta in five months starting from July to November. The water level in the inundated area is about 1 to 3 meters. The average economic losses are estimated at about 40-50 million USD [6].

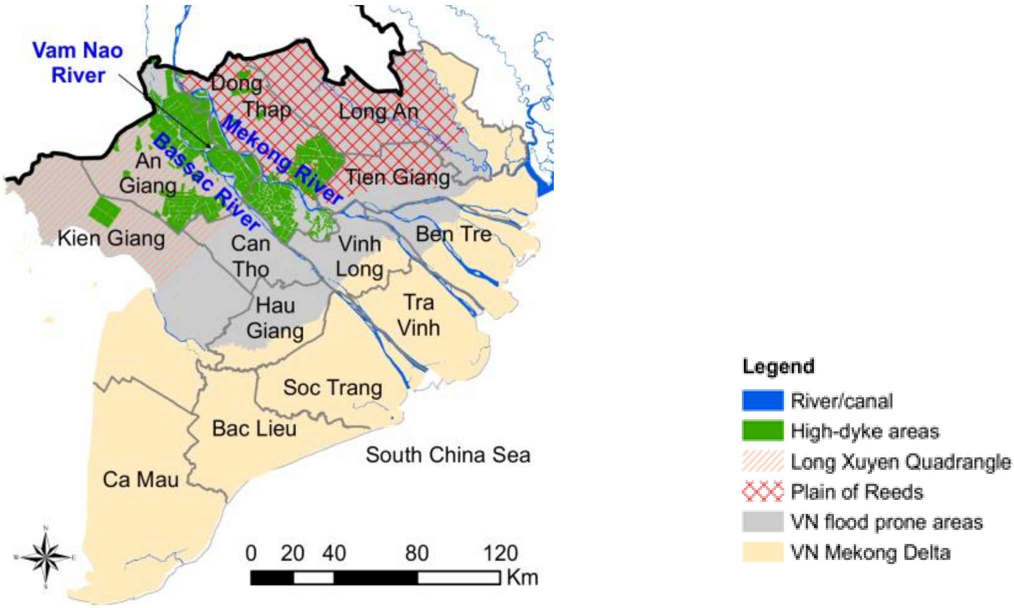

Figure 1. Flood-prone areas in Vietnamese Mekong Delta [4].

The flooding causes serious damages and losses to the transportation. About 50% of communal roads are in flood risk zones. About 65% of national highway in Mekong River Delta is reported to be in a risk of inundation during rainy season, about 50% of which are located at shallow inundation zones with 0.5 – 1.5 m of depth, 10% are in the medium inundation zones with 1.5 – 3.0 m of depth and 5% in deep inundation zones with depth larger than 3.0 m [6].

Figure 2. Road is flooded in Cantho City, 2020.

Assessing vulnerability and risk induced by extreme floods of the road network is a crucial task for developing flood management strategies and climate change adaptation measures. In particular, the determination of which factors have the greatest impact on the road flood risk and evaluation of these factors is necessary. However, there are a lot of disaster-causing factors, and it is unclear how these factors affect each other and directly impact on the flood risk. Hence, quantifying these road flood risk indicators is complicated.

In this paper, all possible flood-causative factors of road flooding have been investigated. Representative indicators have been chosen to reduce the mutual influence and its derivative, including road characteristics, climatic factors, hydrological characteristics, geology environmental factors (topographical characteristics) and social factors (human activities).

The subjective weighting methods based on the Analytic Hierarchy Process (AHP) was used in this study. The methodology of weighting factors determination will be clearly presented. The significant criteria of road flood vulnerability and its weights will be determined. The obtained results will provide essential information for further study in quantitative evaluation of road flood risk consequences and road flood hazard classification.

2. METHODOLOGY

It is particularly important to use an appropriate method to determine the weight of each indicator. At present, the methods for weight calculation are divided into two types including subjective (Delphi method, consistency theorem method, Analytics Hierarchy Process) and objective methods (entropy weight method, projection pursuit method, variable fuzzy method) [7, 8].

The subjective weighting method determines weights completely according to the understanding, knowledge, and judgments of decision-makers to analyze the physical meaning of indices. It can transfer complex and qualitative factors into quantitative, calculable data and then give the relative importance of indices. In contrast, the objective weights totally depend on the input data. The objective weighting method determines the weight by using the difference information of samples. If the input data changes, the objective weights will change correspondingly. When the quality and quantity of the sample data cannot be guaranteed, simply using objective weights is inaccurate [9, 10].

Although the main disadvantage of the subjective method is its potential uncertainty, it is still the most common expert scoring method and widely applied in flood risk assessment. The advantage of this method is its clear concept, simple operation, less required information and decision-making time. For the case of road flood risk in Mekong River Delta with limited information and not many causative indicators, the subjective Analytic Hierarchy Process (AHP) method was applied to determine weights with the help of a preference matrix in this study.

The AHP is a well-known method of determining weights with high accuracy. The AHP method has numerous advantages compared to other multi-objective decision-making methods. The AHP method can check the consistency of indecision-makers' judgment, so the accuracy of the assessment can be ensured and improved when required. In addition, the process of calculating is easy, even for a large number of criteria. The calculation process of the AHP method is composed of four steps including constructing a judgment matrix, hierarchical single ordering, total ordering, and consistency test [11-14].

Constructing judgment matrix: The judgment matrix is constructed through the pairwise comparison between the factors of each layer. It represents the relative importance of factors in a level related to a factor in the higher level. A 9-point scale was constructed as provided by Satty, 1980 [14]. Every input is rated on a 1–9 judgment scale to determine relative importance of the different attributes on one level of the hierarchy to one another.

Table 2. Pair-wise comparison scheme for data collection.

Value of rating judgements	**Verbal judgements**
1	The two parameters are equally important
3	Parameter i is weakly more important than parameter j
5	Parameter i is strongly more important than parameter j
7	Parameter i is very strongly more important than parameter j
9	Parameter i is absolutely more important than parameter j
2, 4, 6, 8	Interval values between two adjacent choices

The judgment matrix X for the case of m decision makers:

$$X = x_{mm} = \begin{bmatrix} x_{11} & x_{12} \dots & x_{1m} \\ x_{21} & x_{22} \dots & x_{2m} \\ \vdots & \vdots \ \ddots & \vdots \\ x_{m1} & x_{m2} \dots & x_{mm} \end{bmatrix} \tag{1}$$

Hierarchical single ordering is used to determine the weights of factors in a level related to a factor in the higher level, by calculating the judgment matrix’s eigenvalues and eigenvector w_i.

Normalized vector Z_i is:

$$Z_i = \sqrt[m]{x_{i1}x_{i2}\dots x_{im}} \quad (2)$$

The weight coefficient of the *i*-th index w_i:

$$w_i = \frac{Z_i}{\sum_{i=1}^{m} Z_i} \quad (3)$$

The largest Eigen root of the judgment matrix:

$$\lambda_{\max} = \sum_{i=1}^{m} \frac{(Xw)_i}{nw_i} \quad (4)$$

Total ordering: Based on the hierarchical single ordering, weights of all the factors in the same level can be determined. The total ordering requires can be calculated from top level to bottom level.

$$W_i = \frac{1}{m}\sum_{j=1}^{m} w_{ij} \quad (5)$$

Where:

Wi is weighting factors of criteria i,

n is number of criteria.

Consistency test is used to assess the consistency of the total ordering results, as well as the hierarchical single ordering. If the consistency of results does not meet requirements, the judgment matrix is needed to be adjusted.

A consistency ratio (CR) must be computed to check the discordances between the pairwise comparisons and the reliability of the obtained weights. The value must be in the required range to be accepted, otherwise it is necessary to recalculate the weight.

$$CR = \frac{CI}{RI} \quad (6)$$

Where:

CR is the consistency ratio, $CR \le 0.1$ for $n \ge 5$;

RI is the random index representing the consistency of a randomly generated pairwise comparison matrix.

Table 3. Random consistency index.

n	1	2	3	4	5	6	7	8
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41

CI is the consistency index. When CI = 0, the judgment matrix has completion consistency, the larger the CI value, the worse the degree of consistency,

$$CI = \frac{\lambda_{max} - n}{n-1} \quad (7)$$

Where λ_{max} represents the sum of the products between the sum of each column of the comparision matrix and the relative weights.

3. RESULTS AND DISCUSSIONS

This section presents results of MCA based on the AHP method to identify the important criteria and determine the weighting factors of importance for each cause of the road flood in Mekong River Delta. Based on the study of the occurred road flood events within Mekong River Delta, five major disaster-causing factors including the road characteristics, climatic factors, hydrological characteristics, geology environmental factors (topographical characteristics) and social factors (human activities) are considered in this paper.

Five experienced experts have been invited to score the index system. Among them, 3 experts have more than 10 years of experience in road or civil engineering, 2 lecturers work in the University of Transport and Communication. Experts analyzed, evaluated and compared the importance of road flood risk indicators. The scores were given from 0 (lowest importance) to 9 (highest importance).

The evaluation matrix given by 1st decision maker is obtained as follows:

$$X_1 = \begin{bmatrix} x_{11} & x_{12} & x_{13} & x_{14} & x_{15} \\ x_{21} & x_{22} & x_{23} & x_{24} & x_{25} \\ x_{31} & x_{32} & x_{33} & x_{34} & x_{35} \\ x_{41} & x_{42} & x_{43} & x_{44} & x_{45} \\ x_{51} & x_{52} & x_{53} & x_{54} & x_{55} \end{bmatrix} = \begin{bmatrix} 1 & 1/4 & 1/2 & 2 & 3 \\ 4 & 1 & 2 & 4 & 4 \\ 2 & 1/2 & 1 & 2 & 3 \\ 1/2 & 1/4 & 1/2 & 1 & 2 \\ 1/3 & 1/4 & 1/3 & 1/2 & 1 \end{bmatrix}$$

The 1st researcher considered that the climatic factors play a moderate higher influence on the road flooding than the road characteristics, topographical characteristics (level of importance is 4) but slightly higher than hydrological characteristics (level of importance is 2). The importance of hydrological characteristics is higher to the road flooding than the topographical characteristics (level of importance is 2) and the social factors are considered to be less important than all the others.

For the road characteristics, climatics factors, hydrological characteristics, geology environmental factors and social factors in this case, the normalized weights w_i are:

$$\begin{bmatrix} 0.13 \\ 0.51 \\ 0.26 \\ 0.06 \\ 0.04 \end{bmatrix}, \begin{bmatrix} 0.11 \\ 0.44 \\ 0.22 \\ 0.11 \\ 0.11 \end{bmatrix}, \begin{bmatrix} 0.12 \\ 0.46 \\ 0.23 \\ 0.12 \\ 0.08 \end{bmatrix}, \begin{bmatrix} 0.21 \\ 0.42 \\ 0.21 \\ 0.11 \\ 0.05 \end{bmatrix}, \begin{bmatrix} 0.23 \\ 0.31 \\ 0.23 \\ 0.15 \\ 0.08 \end{bmatrix}$$

The average normalized weight is: $\begin{bmatrix} 0.16 \\ 0.43 \\ 0.23 \\ 0.11 \\ 0.07 \end{bmatrix}$

The consistency index:

$$CI = \frac{\lambda_{\max} - n}{n-1} = 0.046 \tag{8}$$

As the random consistency index for the case of 5 indicators RCI = 1.12, the consistency ratio is determined as follows:

$$CR = \frac{CI}{RI} = \frac{0.046}{1.12} = 0.041 \tag{9}$$

As $CR = 0.041 \leq 0.1$, the consistency ratio is in the acceptable range. As a result, according to this expert's opinion, road characteristics, climatic factors, hydrological characteristics, topographical characteristics, and social factors were weighted as 16%, 43%, 23%, 11% and 7% importance as the cause of road flood, respectively. These weights of road flooding causing indicators are consistent and no more information of the decision makers or repeated procedure is required.

The calculation process is repeated for the data given by other experts. The evaluation matrixs given by others are:

$$X_2 = \begin{bmatrix} 1 & 1/3 & 1/2 & 1 & 1 \\ 3 & 1 & 2 & 2 & 3 \\ 2 & 1/2 & 1 & 1 & 2 \\ 1 & 1/2 & 1 & 1 & 2 \\ 1 & 1/3 & 1/2 & 1/2 & 1 \end{bmatrix}; \; X_3 = \begin{bmatrix} 1 & 1/3 & 1 & 1 & 2 \\ 3 & 1 & 2 & 2 & 3 \\ 1 & 1/2 & 1 & 1 & 2 \\ 1 & 1/2 & 1 & 1 & 1 \\ 1/2 & 1/3 & 1/2 & 1 & 1 \end{bmatrix};$$

$$X_4 = \begin{bmatrix} 1 & 1/3 & 1 & 1 & 2 \\ 3 & 1 & 1 & 2 & 3 \\ 1 & 1 & 1 & 1 & 2 \\ 1 & 1/2 & 1/2 & 1 & 1 \\ 1/2 & 1/3 & 1/2 & 1 & 1 \end{bmatrix}; \; X_5 = \begin{bmatrix} 1 & 1/3 & 1/3 & 1 & 2 \\ 3 & 1 & 2 & 3 & 4 \\ 3 & 1/2 & 1 & 1 & 2 \\ 1 & 1/3 & 1 & 1 & 2 \\ 1/2 & 1/2 & 1/4 & 1/2 & 1 \end{bmatrix}$$

In the final step, the numerical weighting factors given to the criteria influencing the causes of road flooding were calculated by using the average values of normalized weights of each criterion obtained from all researchers. All the judgment matrix has passed the consistency test; hence the weights are reasonable. The obtained results are presented in Table 4.

Table 4. Results of weights given to the criteria influencing the highway flood.

Criteria	Experts					Average
	1st	2nd	3rd	4th	5th	
Road charateristics	0.16	0.13	0.17	0.17	0.12	0.15
Climatic factors	0.43	0.37	0.37	0.33	0.37	0.37
Hydrological characteristics	0.23	0.21	0.18	0.25	0.20	0.21
Topographical characteristics	0.11	0.18	0.16	0.14	0.15	0.15
Social factors	0.07	0.11	0.11	0.11	0.09	0.10

It can be concluded that based on the AHP method, the climate factors and hydrological characteristics are the most influencing factors to the road flood risk in Mekong River Delta with the weight of 0.37 and 0.21, respectively. The road characteristics and the topographical characteristics are equally weighted as 15% importance as the cause of road flood. The social factor has the least influence on the cause of the road flood with just 10% influence. Based on the obtained results, a more reasonable management plan for road flood risk can be established.

4. CONCLUSIONS

Flood in Mekong River is a recurring event and has an enormous impact on the socio-economic system. Under the effect of climate change, the transportation infrastructure including the road network could be damaged directly and indirectly. In this study, the major causes of road flooding in Mekong River Delta are road characteristics, climatic factors, hydrological characteristics, geology environmental factors and social factors. The subjective method based on the Analytic Hierarchy Process was applied to quantify the weights of road flood disaster-causing factors as well as its impact. The climate factors were found as the most important criteria that influences the cause of the road flood with the highest weight of 0.37. These obtained weighting factors can be used for the multi-index evaluation, classifying the degree of road flood risk and provide references for decision-making in the road flood management to prevent and decrease the losses of flood disaster. In further studies, other methods such as objective and combined methods could be applied to improve the accuracy of the road flood risk analysis results.

ACKNOWLEDGMENT

This research is funded by University of Transport and Communications (UTC) under grant number T2021-CT-008TD.

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