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Flood Vulnerability Index Based on Indicator Approach in Assessing Flood Risk in Selangor, Malaysia

Nur Farah Asyiqin Tajuddin[1], Zatil Izzah Ahmad Tarmizi[1], Faizah Che Ros[1,2]*, Shuib Rambat[1,2], Nurul Zainab Along[1,2], Aizul Nahar Harun[1,3]

[1] *Environmental Resilience & Sustainability Ikohza, Malaysia-Japan International Institute of Technology, UTM, 54100 Kuala Lumpur, MALAYSIA*

[2] *Department of Chemical & Environmental Engineering, Malaysia-Japan International Institute of Technology, UTM, 54100 Kuala Lumpur, MALAYSIA*

[3] *Department of Management of Technology, Malaysia-Japan International Institute of Technology, UTM, 54100 Kuala Lumpur, MALAYSIA*

*Corresponding Author: crfaizah@utm.my
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Abstract

Floods are one of the most common and damaging natural disasters, claiming lives, and causing significant economic damage. Urbanization can increase the risk of flooding due to increased water runoff and volume. This study focuses on a flood vulnerability assessment approach as a planning tool by combining the Flood Vulnerability Index (FVI) with variables available in urban development areas. This index was created by combining the variables of three components: exposure, susceptibility, and resilience. FVI is a critical element in risk management and flood damage assessment. Vulnerability is described in FVI research as the amount of damage that can be predicted under conditions of exposure, susceptibility, and resilience. Vulnerability studies frequently use an indicator-based vulnerability assessment to estimate the complexity and degree of risk. FVI reflects the vulnerability of urban areas. Secondary data were used to obtain variables for the social and economic components. A quantitative method was used to calculate the correlation of each variable with flooding via the Statistical Package for the Social Sciences (SPSS). The indicators are categorized as exposure, susceptibility, and resilience, and these indices were created using normalization, weighting, and aggregation of the indicators. To determine the flood vulnerability in Selangor, a small number of indicators were selected to quantitatively assess the flood risk in Selangor. Based on calculated FVI, the vulnerability of the districts in Selangor has been ranked and categorized from high to very low. The result shows Gombak and Klang are the most vulnerable districts in Selangor to flooding because of their high exposure to flooding. The results of this study could serve as a reference tool for future flood risk mitigation efforts in Selangor.

1. Introduction

The central concept in flood risk management is vulnerability. Vulnerability studies attempt to discover relevant mitigation measures prior to the occurrence of a possible hazard [1]. The FVI is a useful tool for policymakers and decision-makers to use to prioritize investments and promote flexibility in decision-making. Finding locations with a high risk of flooding could help societies make decisions that would improve how they deal with floods [2]. Thus, the assessment of a region's vulnerability to floods includes two major stages: the vulnerability is assessed by grouping it into categories like natural, economic, and social vulnerability. Because every society is vulnerable to flooding under a variety of flood scenarios and geographical and climatic conditions, each one is slightly distinct from the others. Understanding the gaps and the regularity in which they occur may assist in advance planning and provide policy recommendations to improve the quality of life for those who live in or near flood-prone areas.

In Malaysia, there has been little research on risk assessment regarding reducing flood risks [3]. The current FVI emphasizes a great deal on the river basin scale while ignoring some of the elements that make urban areas and sub-catchments vulnerable to flooding. The various scales are vulnerable to flooding due to a variety of factors. The approach is currently being evaluated at the urban, sub- catchment, and river basin scales. Therefore, the main purpose of flood risk management is to bring these human casualties and financial expenditures down to a manageable level [4]. Numerous techniques have been developed by researchers to determine flood vulnerability. Despite greater knowledge of the vulnerability, the risk of flooding is still relatively pervasive. The vulnerability of an area to flooding is determined by environmental, cultural, social, and even political factors that are difficult to quantify [5].

The Geographic Information System (GIS) was used to create the most widely used flood vulnerability index in Malaysia, whereas other locally conducted studies used an indicator-based methodology. The large sets of indicators used in the indicator-based method for calculating flood vulnerability, as well as the exclusion of some indicators that may reflect an overly conservative or understated interpretation of flood vulnerability or the homogeneity of vast areas, are included in the flood vulnerability index. Flood risks should be managed because they cannot be entirely minimized. The choice of indicators, which depends on the availability of secondary data and relevance, can define whether a region is vulnerable to flooding. This study focused on flood risk using the flood vulnerability index indicator-based method of secondary data by using the Statistical Package for the Social Sciences (SPSS) and rating the vulnerability within the study area. The study was conducted in one of Malaysia's major cities, Selangor, which is affected by flooding on an annual basis.

2. Literature Review

2.1 Flood Vulnerability Index

The Flood Vulnerability Index (FVI) is a vulnerability to flooding assessment tool that groups several elements that determine the risk of flood-prone people based on river basins, sub-basins, and urban areas. Using existing data, understanding the components of flood susceptibility could be enhanced. Previous indices highlighted four key social, economic, environmental, and physical components, each of which is represented by various indicators [6].

Connor & Hiroki [7] made this assessment for river basins and claimed that there are many other elements besides rainfall and runoff that determine the flood vulnerability of a basin, such as preparedness and resilience. Balica [6] identified four other components for these two scales: economic, environmental, social, and physical, which can be measured with different metrics. The flood risk index is based on the interaction of these components and the specific factors of the system (exposure, susceptibility, and resilience). This is the basis of the flood vulnerability index.

$$\text{Vulnerability} = \text{Exposure} + \text{Susceptibilty} - \text{Resilience} \quad (1)$$

The result is that flood risk is closely linked to people's vulnerability, events, and inability to cope with the consequences. For example, vulnerability to flooding is defined by several criteria, including the severity of the flood event, the level of risk associated with the hazard, and the damage caused by the event. In Malaysia, Liew & Che Ros [8] developed the FVI on national level excluding Sabah and Sarawak. The basis of FVI is as described by Balica [6].

3. Material and Methods

3.1 Study Area

Selangor is generally a vulnerable area. It is located between the Titiwangsa Range and the Straits of Malacca. Selangor's central location in Peninsular Malaysia supports the state's rapid development as Malaysia's industrial and logistic hub. Selangor's capital is Shah Alam, and Klang is the royal capital. The state is divided into nine districts and twelve cities, as shown in Fig. 1.

Fig. 1 *State of Selangor and its districts*

Selangor is the most populous state in Malaysia, contributed by the country's largest coalition city, the Klang Valley. This rapid development has an impact on urban areas. The population of Selangor has been growing at a rapid rate in recent years due to the rapid development in the Klang Valley, which has had a huge impact on Selangor's development. The absence of an adequate buffer zone after the opening of a large area has led the existing development to be built nearby or in the flood- sensitive zone area. Selangor no longer experiences significant flooding from river overtopping because of comprehensive flood control initiatives put out inside the main river basins by the Department of Irrigation and Drainage.

Flash floods, however, continue to plague the state, especially in places where there is construction or sand mining activity. Flash floods are more common due to the current surge in urban expansion and buildings. The most recent flooding in Selangor occurred around November 2022 and hit Klang, Shah Alam, Puchong, and Kajang. The heavy downpour has led tolandslides and rising water levels in several areas [9]. The floods in Selangor are not showing any improvement in decreasing either. The floods recorded the highest in 2015, followed by 2018 as shown in Table 1. It showed an unstable pattern but not a positive pattern. Besides, among the districts in Selangor, Klang showed the most consistent increase in cases over the years, as shown in Table 1. Klang records the most cases, unless in 2019, which is in Gombak; even in the latest flooding in November 2022, Klang was one of the areas affected.

Table 1 *List of flood events in Selangor by district [10]*

District	2014	2015	2016	2017	2018	2019	2020
Gombak	11	30	12	20	26	34	45
Hulu Langat	6	16	21	29	20	14	44
Hulu Selangor	15	8	4	10	8	9	12
Klang	17	45	33	25	10	26	59
Kuala Langat	7	7	3	2	6	1	12
Kuala Selangor	6	11	7	9	16	5	28
Petaling	17	35	13	11	32	18	20
Sabak Bernam	6	2	2	23	23	0	14
Sepang	7	17	5	12	10	4	32

3.2 Application of Methods

In this research, we perform a multivariate analysis to evaluate the correlation, multicollinearity, and reliability of the indicator chosen. Due to the correlation between the independent variables in a regression model, multicollinearity was selected for this study. The relationship among the variables is difficult to achieve because independent variables should be independent. If the relationship between factors is strong enough, applying the model and understanding the data can be difficult [11].

3.3 Selection of Indicators

According to the flood vulnerability index, an indicator-based methodology with three major components—exposure, susceptibility, and resilience—the suitable indicators were chosen while keeping in mind their relevance to the study and the availability of data (Table 1). The data selections were primarily taken from publicly available sources, such as the Department of Irrigation and Drainage rainfall statistics (DID). The other indicators were taken from different government agencies, such as the Ministry of Health (MOH), Department of Agriculture (DOA), Department of Statistics Malaysia (DOSM), and Ministry of Home Affairs (Table 2).

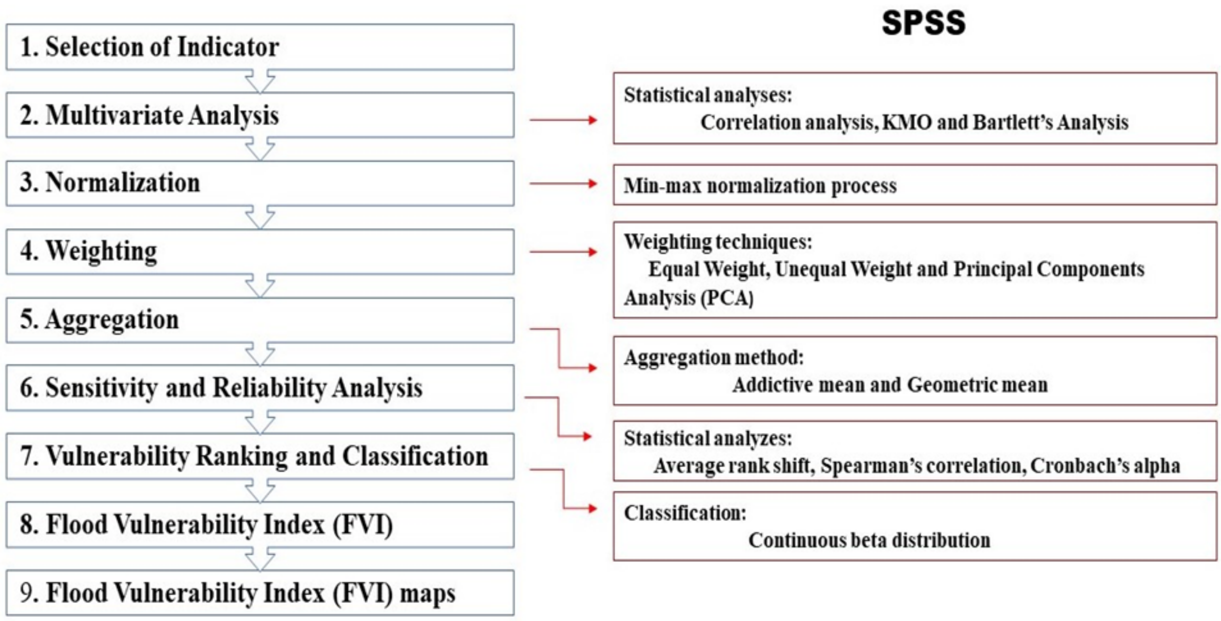

Fig. 2 *Methodology workflow*

Table 2 *General list of indicators selected*

Factors	Indicator	Sources	Period
Exposure	E1) Frequency of flooding	DID	2013-2020
	E2) Flood Prone Area	DID	2021
	E3) Population Density in Flood Prone Area	DID	2021
	E4) Average Recurrence Interval (ARI)	DID	2000-2021
	E5) Maximum Daily Rainfall	DID	2000-2021
Susceptibility	S1) Population Density	DOSM	2021
	S2) Disabled Person	JKM	2021
	S3) House Conditions	DOSM	2021
	S4) Agriculture Workers	DOSM	2021
	S5) Inequality	DOSM	2021
Resilience	R1) Land Use	DOA	2017
	R2) Emergency Services	MOH	2021
	R3) Internet Access	DOSM	2019
	R4) Household Median Income	DOSM	2022

According to a few other studies that chose to perform flood vulnerability indexes using the indicators methodologies, the indicators used in this study were chosen. The indicators are predominantly drawn from secondary approaches that other researchers have adopted, and they are primarily drawn from popular options among researchers. One of the most well-liked selections of indicators is shown on the list.

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3.4 Calculation of Flood Vulnerability Index (FVI)

The normalization calculation of the vulnerability index according to each indicator using linear transformations in Eq. (2) or Eq. (3).

$$y_{ij} = \frac{x_{ij} - x_{\min}}{x_{\max} - x_{\min}} \tag{2}$$

$$y_{ij} = \frac{x_{\max} - x_{ij}}{x_{\max} - x_{\min}} \tag{3}$$

The normalized weights produced from the AHP were used to calculate the vulnerability index for each component with equal and unequal weighting, i.e., Eq. (4) and Eq. (5), and then aggregation based on the addition of the components with equal weights, which was employed completely.

$$w_{ij} = \frac{c}{\sqrt{\operatorname{var}\left(y_{ij}\right)}} \tag{4}$$

$$c = \sum_{j=i}^{k} \frac{1}{\sqrt{\operatorname{var}\left(y_{ij}\right)}} \tag{5}$$

Geometric aggregation is a nonlinear technique that is determined as the product of weighted indicators. As a result, the conceptual FVI equation can be represented as either an additive mean in Eq. (6) or a geometric mean in Eq. (7).

$$FVIa = \sum\nolimits^{n}{}_{j=1} w_j y_{ij} = \frac{1}{3}\left(EI + SI + RI\right) \tag{6}$$

$$FVIg = \sum\nolimits^{n}{}_{j=1} w_{ij} y_{ij} = \left(EI \times SI \times RI\right)\frac{1}{3} \tag{7}$$

Then, utilizing the sensitivity and reliability analyses, continue with the calculation. The average rank shift is a sensitivity analysis approach used to assess the composite indicator's robustness. The rank shift, Rs, defines the uncertainty of each input factor, and the mean is derived in Eq. (8) as the variance between the rank of each state and the reference rank divided by the total number of states (m). Taking bound rankings into account, the Spearman's correlation coefficient, r, is provided in Eq. (9).

$$Rs\frac{1}{m} = \sum_{j=1}^{m} Rank_{ref}\left(FVI\right) - Rank\left(FVIi\right) \tag{8}$$

$$p = \frac{12\left(\sum\nolimits^{n}{}_{j=1} R_i S_i - n\left(n+1\right)\frac{2}{4}\right)}{\left[n\left(n^2-1\right) - 12t^1\right]\left[n\left(n^2-1\right) - 12u^1\right]\frac{1}{2}} \tag{9}$$

Finally, before the ranking and classification, Cronbach's alpha a was applied to assess the reliability or consistency of the ranks, as shown in Eq. (10) and Eq. (11). Cronbach's alpha can be influenced by the variety of ranking systems used and the average intercorrelation between them. An alpha number greater than 0.9 shows that the rankings are quite consistent, but a value less than 0.7 is questionable. Cronbach's alpha equation has been put in.

$$t' = \sum t\left(t^2 - 1\right) \tag{10}$$

$$u' = \sum u\left(u^2 - 1\right) \tag{11}$$

4. Results and Discussion

The result of flood vulnerability at district level was investigated, thus aiming for the objective of this study. Vulnerability assessments through the indicator-based approach provide an overview of the social, economic, and environmental determinants for the districts that are vulnerable to the flood. In this study, the indicator approach enables the relative ranking and classification of flood vulnerability among the districts in Selangor. Indicators relate to exposure; vulnerability and resilience were constructed to capture the multidimensionality of vulnerability.

4.1 Flood Vulnerability at District Level

The underlying contributing causes of vulnerability at the district level are explored in the next section after the validation of the selected indicators and statistical analyses of the ranking and classification. The tendency of a state to be interrupted by flooding disasters due to its location is referred to as exposure. The level to which components within the system are exposed and likely to be affected is defined as susceptibility. Resilience is a state of being able to withstand any disturbance while remaining efficient in its social and economic components. The FVI decomposes into three factors of vulnerability and each indicator is assessed within its vulnerability category.

Table 3 *Decomposition of flood vulnerability according to indicators*

District	Exposure	Susceptibility	Resilience
Klang	Very High	Low	High
Gombak	Very High	Moderate	Very High
Hulu Langat	High	Very Low	High
Sepang	High	High	Very High
Kuala Langat	Moderate	Low	Moderate
Sabak Bernam	Moderate	Very High	Very Low
Kuala Selangor	Low	Very High	Low
Petaling	Low	Moderate	Moderate
Selangor	Very Low	High	Low

Klang is ranked the most vulnerable district because of its high exposure, low susceptibility, and high resilience. Likewise, Gombak and Hulu Langat exhibit high and moderate susceptibility and very high resilience, so they are identified as the most vulnerable districts. Then, in the moderate susceptibility category, Kuala Langat and Sabak Bernam are exposed moderately, and due to their low susceptibility, these districts are considered moderate. On the other hand, Kuala Selangor, Petaling, and Hulu Selangor exposures are very low.

5. Conclusion

In this study, the Flood Vulnerability Index (FVI) was put into effect at the district level. The selected indicators could explain the association with flood vulnerability because they were statistically significant. Three alternative weighting methods and two aggregation methods were used to test the stability of the FVI methodology. For ranking and classification functions, the FVI computed in this study using equal weighting approaches and the addicted mean method is remarkably reliable. The advantage of the composite indicator approach is that it may measure the degree of vulnerability across Selangor's districts by distilling complicated matters into a single number. The study shows that Gombak and Klang are the most vulnerable districts in Selangor to flooding because of their high exposure to flooding, and it also discusses the contributing factors that make these districts more sensitive to flooding.

To achieve the goal of this study, the contributing parameters of district-level flood risk were analyzed. The indicator-based method for vulnerability assessments gives a broad perspective of the social, economic, and environmental variables for the districts that are at risk from flooding. The indicator approach used in this study makes it possible to rank and categorize the districts in Selangor according to their relative flood danger. To represent the multidimensionality of vulnerability, indicators relating to exposure, susceptibility, and resilience were created.

Gombak and Klang are the most vulnerable districts in Selangor to flooding because of their high exposure. The flood-prone area and the population density in the flood-prone area, as well as the average recurrence interval (ARI), are variables that influence vulnerability in the exposure factors, The outcome of this study could become a discussion that raised awareness in providing disaster education for stakeholders and local community. The findings and outcome of the study also can serve as a reference tool for future flood risk mitigation efforts in Selangor.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Nur Farah Asyiqin Tajuddin, Faizah Che Ros;* ***data collection:*** *Nur Farah Asyiqin Tajuddin, Aizul Nahar Harun;* ***analysis and interpretation of results:*** *Nur Farah Asyiqin Tajuddin, Faizah Che Ros, Zatil Izzah Ahmad Tarmizi;* ***draft manuscript preparation:*** *Nur Farah Asyiqin Tajuddin, Shuib Rambat, Nurul Zainab Along. All authors reviewed the results and approved the final version of the manuscript.*

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