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SPATIAL FLOOD VULNERABILITY ASSESSMENT IN PENINSULAR MALAYSIA USING DATA ENVELOPMENT ANALYSIS (DEA)

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Abstract

Flood has caused an enormous negative impact on the environment and the population safety in Malaysia. Many areas are found to be vulnerable to flood due to heavy rainfall during monsoon seasons. However, not many studies were done to identify how vulnerable the prone areas are affected. This study focused on developing flood vulnerability measurement in Peninsular Malaysian states. Data Envelopment Analysis (DEA) was applied on a set of secondary data consisting of several input and output variables across 11 years from 2004 to 2014. The flood vulnerability index for each dimension was computed based on three aspects of flood vulnerability dimensions, i.e. the Population Vulnerability, the Social Vulnerability and the Biophysical Vulnerability. The result showed that Johor was the most vulnerable state among all the states in Peninsular Malaysia in terms of the Population Vulnerability. Meanwhile, Kelantan was the most vulnerable state in the Social Vulnerability and Kedah was the most vulnerable state in the Biophysical Vulnerability. The assessment of flood vulnerability can provide multi-information that may well contribute to a deeper understanding of flood disaster scenario in Malaysia.

Keywords: *Multi-Dimensional, Flood Vulnerability, Data Envelopment Analysis, DEA*
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1.0 Introduction

In Malaysia, flood disaster becomes the worst natural hazards. Malaysia is one of the countries that have the most rainfall in the world. Since 1971, Malaysia is often facing severe flooding (Khalid *et al.*, 2015). Due to unpredictable factors of climate change such as rainfall and temperature, the Malaysian Government continues to have an issue of flood prevention and flood policies even though several methods and ways have been performed (Shafiaia & Khalid, 2016). A monsoon flood will occur during the monsoon season when there is heavy rainfall in October to February of each year. The areas in the East Coast states are commonly affected during this season. Moreover, improper drainage facilities in the areas of the development site have also increased the severity of flood (Hua, 2014).

2.0 Literature Review

Flood vulnerability is one of the main components of flood risk assessment and flood damage analysis in the aspects of ecological, community, financial and physical (Nasiri *et al.*, 2013). Generally, vulnerability is defined as the potential for loss when a disaster has occurred (Sané *et al.*, 2015). Flood vulnerability assessment has been studied in several developed countries, yet, in Malaysia, there is limited knowledge of vulnerability in a natural disaster. Although the flood prone areas in Malaysia are well identified, however, there is still a lack of appropriate measurement to identify how vulnerable the prone areas will be affected (Akukwe & Ogbodo, 2015).

Visualization tool such as Weighted Linear Combination methods in Geographic Information System (GIS) and Moderate Resolution Imaging Spectroradiometer (MODIS) are commonly approaches used in flood vulnerability assessment. Currently, the existing quantitative methods are very sensitive to weights of sub-indices which the calculation of weighting depends on arbitrary decisions. This will reduce the confidence, which can be placed in such weighting methods. (Wei *et al*., 2004).

3.0 Methodology

Data Envelopment Analysis (DEA) is a powerful approach to measure efficiency of decision making units (DMUs) with a set of input and output variables (Khodabakhshi & Asgharian, 2008). The use of DEA is still new in the natural disaster analysis. However, the efficiency result can reflect the vulnerability level in natural disaster analysis (Wei *et al*., 2004). The flood vulnerability can be calculated by the ratio between the input and output variables which the process of flood hazard is observed as "input-output" system (Huang *et al*., 2012). Normally, flood vulnerability is described as the degree of damage by flood disaster. A range scale of 0 to 1 is used as the indicator reading to explain the vulnerability level of DMUs (Nasiri & Shahmohammadi-Kalalagh, 2013).

In this study, 11 states in Peninsular Malaysia were selected as the DMUs by using the secondary data (2004 to 2014). Three dimensions were focused in this study based on the previous research and the data availability; (1) Population Vulnerability, (2) Social Vulnerability and (3) Biophysical Vulnerability. The selected inputs and outputs were shown in Table 1. The data of inputs and outputs were collected from Department of Statistics Malaysia (DOSM), National Security Council, Malaysia Meteorological Department (MeTMalaysia) and Department of Social Welfare.

Table 1: List of Input and Output

Dimensions	Variables		Descriptions
Population Vulnerability	Input	Total Rainfall (mm)	Number of total rainfall in each Peninsular Malaysian states.
	Output	People Affected	Number of people affected being reported in each Peninsular Malaysian states.
Social Vulnerability	Input	Total Rainfall (mm)	Number of total rainfall in each Peninsular Malaysian states.
	Output	People's Death	Number of people's death being reported in each Peninsular Malaysian states.
Biophysical Vulnerability	Input	Total Population	Number of individuals in each Peninsular Malaysian states.
		Rate of Crop Area (hectare)	Number of crop area width in each Peninsular Malaysian states.
	Output	Areas Affected (hectare)	Number of areas affected width in each Peninsular Malaysian states.

DEA model was measured using the Efficiency Measurement System (EMS) software. Based on the efficiency range scale of 0 to 1, the vulnerability score of 1 is concluded as the most vulnerable to flood disaster and the vulnerability score approach to 0 is concluded as the least vulnerable to flood disaster (Nasiri & Shahmohammadi-Kalalagh, 2013). Generally, the efficiency score of a DMU is measured in terms of the ratio of the sum of weighted outputs to the sum of weighted inputs as follows:

$$\text{Efficiency} = \frac{\text{sum of weighted outputs}}{\text{sum of weighted inputs}} \tag{1}$$

Constant Return to Scale (CRS) DEA model was developed in this study for Population Vulnerability, Social Vulnerability and Biophysical Vulnerability. The CRS DEA model is shown as below:

$$\begin{aligned}&Min\ \ \theta\\&subject\ to\\&\sum_{j=1}^{n}\lambda_j x_j + s^- = \theta x_0\\&\sum_{j=1}^{n}\lambda_j y_j + s^+ = y_0\\&\lambda_j \geq 0,\ j = 1,2,...n, s^+ \geq 0, s^- \geq 0\end{aligned} \tag{2}$$

Where θ is the vulnerability score ($0 < \theta \leq 1$), x and y are the input and output variables, n is the number of DMUs ($n = 1,2,...,11$), λ_j is the weight attached for input and output variables, s^- is a slack for input and s^+ is a slack for output. In Population Vulnerability for example, there is one input (x_{1n}) and one output (y_{1n}) for each state. For a state, n = 1, the input is stated as x_{11} and the output is stated as y_{11}. The Eq. (2) is modified as follows:

$$\begin{aligned}&Min\ \ \theta\\&subject\ to\\&-y_{11} + (y_{11}\lambda_1 + y_{12}\lambda_2 + y_{13}\lambda_3 + ... + y_{1n}\lambda_n) \geq 0,\\&\theta x_{11} + (x_{11}\lambda_1 + x_{12}\lambda_2 + x_{13}\lambda_3 + ... + x_{1n}\lambda_n) \geq 0,\\&\lambda \geq 0,\end{aligned} \tag{3}$$

Where n is equal to 11 and $\lambda = (\lambda_1, \lambda_2, \lambda_3, ..., \lambda_{11})$. Based on the Eq. (3), the minimum value for θ is measured. For this example, the θ value is the vulnerability score for the Population Vulnerability in the Peninsular Malaysian state of n = 1. If the value of θ is equal to one, the state will be concluded as the highest population vulnerability and if the value of θ closer to 0, the state will be concluded as the lowest population vulnerability.

4.0 Results and Discussions

Using the DEA analysis, the first objective of this study is to determine the flood vulnerability score based on the three different dimensions in each Peninsular Malaysian states. The results from the DEA analysis are shown in Table 2, Table 3 and Table 4. From Table 2, the yearly vulnerability score of Population Vulnerability for each state was shown. Take the example from the year 2004: (1) The most vulnerable state of flood disaster was Terengganu with a vulnerability score of 1.000. (2) The least vulnerable state of flood disaster was Perlis with a vulnerability score of 0.500.

Table 2: Vulnerability Score of Peninsular Malaysian States for Population Vulnerability

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Johor	0.684	0.539	**1.000**	0.668	0.737	**1.000**	0.556	**1.000**	0.547	0.533	0.502
Kedah	0.606	0.927	0.589	0.700	0.620	0.540	0.714	0.534	0.527	0.569	0.500
Kelantan	0.773	0.516	0.555	0.604	0.922	0.687	0.540	0.526	0.710	0.591	**1.000**
Melaka	0.507	0.610	0.563	0.503	0.531	0.519	0.732	0.580	0.547	0.502	0.503
Negeri Sembilan	0.508	0.502	0.503	0.506	0.517	0.515	0.567	0.516	0.511	0.502	0.501
Pahang	0.530	0.515	0.558	**1.000**	**1.000**	0.573	0.540	0.699	0.548	**1.000**	0.564
Pulau Pinang	0.512	0.501	0.501	0.505	0.801	0.539	0.509	0.504	0.516	0.578	0.501
Perak	0.526	0.512	0.508	0.507	0.520	0.510	0.506	0.506	0.513	0.540	0.526
Perlis	0.500	**1.000**	0.500	0.500	0.500	0.509	**1.000**	0.756	0.500	0.500	0.502
Selangor	0.513	0.507	0.505	0.512	0.582	0.506	0.505	0.504	0.610	0.503	0.501
Terengganu	**1.000**	0.519	0.549	0.516	0.637	0.659	0.510	0.520	**1.000**	0.886	0.595

In Table 3, the vulnerability score of Social Vulnerability for each state was shown in yearly basis. From the year 2004 as the example, the results were concluded: (1) The most vulnerable state of flood disaster was Kelantan with a vulnerability score of 1.000. (2) The least vulnerable state of flood disaster was Selangor with a vulnerability score of 0.508.

Table 3: Vulnerability Score of Peninsular Malaysian States for Social Vulnerability

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Johor	0.511	0.565	**1.000**	0.503	0.956	0.547	**1.000**	0.506	0.520	0.543	0.504
Kedah	0.555	0.651	0.519	0.514	0.686	0.567	0.578	**1.000**	0.547	0.595	0.506
Kelantan	**1.000**	**1.000**	0.503	0.660	0.807	0.516	0.525	0.506	0.523	**1.000**	**1.000**
Melaka	0.527	0.569	0.507	0.506	0.638	0.579	0.586	0.530	0.587	0.720	0.515
Negeri Sembilan	0.519	0.552	0.506	0.505	0.586	0.574	0.574	0.517	**1.000**	0.615	0.510
Pahang	0.632	0.847	0.504	**1.000**	**1.000**	**1.000**	0.529	0.507	0.519	0.859	0.593
Pulau Pinang	0.520	0.562	0.507	0.505	0.593	0.560	0.597	0.527	0.585	0.671	0.514
Perak	0.679	0.571	0.508	0.507	0.613	0.544	0.549	0.514	0.546	0.606	0.508
Perlis	0.561	0.681	0.515	0.507	0.642	0.586	0.611	0.534	0.611	0.778	0.520
Selangor	0.508	0.523	0.502	0.502	0.520	0.516	0.519	0.505	0.669	0.543	0.503
Terengganu	0.692	0.525	0.503	0.502	0.732	0.626	0.739	0.505	0.691	0.881	0.634

The vulnerability score of Biophysical Vulnerability for each state in yearly basis was shown in Table 4. For the year 2004 as the example, the results were concluded: (1) The most vulnerable states of flood disaster were Kedah and Pulau Pinang with a vulnerability score of 1.000. (2) The least vulnerable states of flood disaster were Melaka, Negeri Sembilan, Perlis and Selangor with a vulnerability score of 0.667.

Table 4: Vulnerability Score of Peninsular Malaysian States for Biophysical Vulnerability

	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Johor	0.865	0.799	0.683	0.896	**1.000**	0.667	0.667	0.667	0.667	0.667	**1.000**
Kedah	**1.000**	0.684	0.834	0.700	**1.000**	0.694	0.967	0.747	0.667	0.667	**1.000**
Kelantan	0.692	0.809	0.887	**1.000**	0.786	0.846	0.670	0.671	0.667	0.714	0.667
Melaka	0.667	0.670	0.689	0.669	0.667	0.667	**1.000**	0.667	0.667	0.667	0.667
Negeri Sembilan	0.667	0.669	0.693	0.671	0.667	0.667	0.667	**1.000**	0.667	0.715	0.667
Pahang	0.757	0.713	0.672	0.680	**1.000**	0.780	0.667	0.750	**1.000**	**1.000**	0.667
Pulau Pinang	**1.000**	0.667	0.668	0.667	0.667	0.667	0.667	0.667	0.667	0.667	0.667
Perak	0.813	0.667	0.668	0.667	0.667	0.667	0.667	0.667	0.865	0.667	0.667
Perlis	0.667	0.668	0.677	0.667	0.667	0.667	0.667	**1.000**	0.670	0.672	0.667
Selangor	0.667	0.667	0.668	0.667	0.667	0.667	0.667	0.667	0.805	0.667	0.667
Terengganu	0.853	**1.000**	**1.000**	0.812	0.676	**1.000**	0.753	0.705	0.703	0.684	0.667

Second objective of this study is to compare the differences in flood vulnerability score across Peninsular Malaysian states. The average vulnerability score for each state across the eleven years was used to compare the difference in each dimension. Table 6 indicates that Johor was the most vulnerable state to the flood disaster among 11 states in Population Vulnerability, while, Kelantan was stated as the most vulnerable state to the flood disaster in Social Vulnerability. It was also found that Kedah was the most vulnerable state to the flood disaster in comparison to the rest of the states in terms of Biophysical Vulnerability.

Eleven states of Peninsular Malaysia in the Population Vulnerability, Social Vulnerability and Biophysical Vulnerability were divided into four levels based on the standard deviation and the mean of average vulnerability score for each dimension. A "very high vulnerability" state was grouped based on the state with the vulnerability score that is at least one standard deviation greater than the mean. Next, a "high vulnerability" states was grouped based on the state with the vulnerability score range from the mean plus one standard deviation. Then, a "medium vulnerability" state was grouped based on the state with the vulnerability score range from the mean minus one standard deviation to the mean. Lastly, a "low vulnerability" state was grouped based on the state with the vulnerability score that is less than the mean minus one standard deviation (Huang *et al*., 2012).

Table 6: Average Vulnerability Score of Peninsular Malaysian States for Multi-Dimensional Flood Vulnerability across Eleven Years

	Population Vulnerability	Social Vulnerability	Biophysical Vulnerability
Johor	0.706	0.651	0.780
Kedah	0.621	0.611	0.814
Kelantan	0.675	0.731	0.764
Melaka	0.554	0.569	0.700
Negeri Sembilan	0.513	0.587	0.704
Pahang	0.684	0.726	0.790
Pulau Pinang	0.543	0.558	0.697
Perak	0.516	0.559	0.698
Perlis	0.615	0.595	0.699
Selangor	0.522	0.528	0.679
Terengganu	0.672	0.639	0.805

In Population Vulnerability, the mean and standard deviation are 0.577 and 0.201 respectively, while, in Social Vulnerability, the mean and standard deviation are 0.141 and 0.316 respectively. Referring to Biophysical Vulnerability, the mean and standard deviation are 0.229 and 0.347 respectively. Table 7 shows the categorization of levels for each dimension.

Table 7: Multi-Dimensional Flood Vulnerability Level

	Population Vulnerability	Social Vulnerability	Biophysical Vulnerability
Very High	1.000 - 0.756	1.000 - 0.765	1.000 - 0.856
High	0.755 - 0.603	0.764 - 0.615	0.854 - 0.738
Medium	0.602 - 0.450	0.614 - 0.465	0.737 - 0.620
Low	0.449 - 0.000	0.464 - 0.000	0.619 - 0.000

Fig. 1 illustrates the flood vulnerability maps for each dimension. Each state was shaded based on the average vulnerability score across the eleven years that was grouped by the flood vulnerability level in Table 7. In Population Vulnerability, the results were concluded: (1) Perlis, Kedah, Kelantan, Terengganu, Pahang and Johor were grouped in "high population vulnerability". The results in Social Vulnerability show: (1) Kelantan, Terengganu, Pahang and Johor were grouped in "high social vulnerability". For Biophysical vulnerability, the results show: 1) Kedah, Kelantan, Terengganu, Pahang and Johor were grouped in "high biophysical vulnerability".

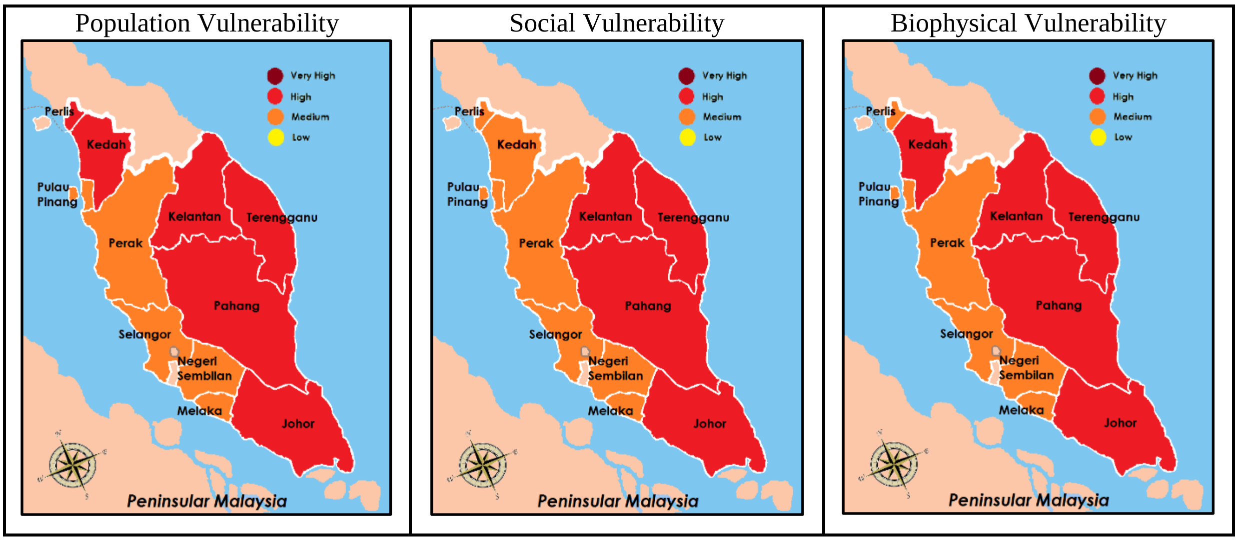

Figure 1: Multi-Dimensional Flood Vulnerability Mapping in Peninsular Malaysia

5.0 Conclusion

This study was focused on multi-dimensional of flood vulnerability assessment for each Peninsular Malaysian states of Population Vulnerability, Social Vulnerability and Biophysical Vulnerability for the period of 2004 to 2014. The results show that Perlis, Kedah, Kelantan, Terengganu, Pahang and Johor were the most vulnerable to flood among the eleven states in terms of Population Vulnerability. Meanwhile, Kelantan, Terengganu, Pahang and Johor were the most vulnerable to flood in Social Vulnerability. In Biophysical Vulnerability, Kedah, Kelantan, Terengganu, Pahang and Johor were the most vulnerable to flood among the eleven states. Further multi-dimensional flood vulnerability assessments using DEA method should be studied in future research to get a deeper understanding of flood vulnerability. Moreover, multi-dimensional flood vulnerability such as economic vulnerability, transportation vulnerability and industrial vulnerability will give better efficient result since for each different output variable by using the same input variables may give different effect of disaster loss.

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