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Flood Vulnerability Assessment Using Data Envelopment Analysis

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ABSTRACT

Flood disaster had caused a great damage to Malaysia. This research focuses on the development of vulnerability measures of the flood disaster in Kelantan. A non-parametric is used for Data Envelopment Analysis (DEA) method only. Secondary data involving a set of inputs and outputs of ten Kelantan's districts covering a seven year period ranging from year 2008 to 2014 are used in the study. The population vulnerability index for each district is computed. Results show that Kuala Krai and Pasir Mas are the most vulnerable districts among all districts in Kelantan. The assessment of flood vulnerability at provincial or national levels can provide manifold information that could contribute to an insightful understanding of the flood disaster in Malaysia.

Keywords: Vulnerability, Data Envelopment Analysis, Efficiency

INTRODUCTION

Flood is one of the severe natural disasters in Malaysia. Despite the fact that the Malaysian Government has implemented various flood mitigation and drainage projects, Malaysia kept on having issues concerning floods (Rahman, 2014). The Malaysian Government fails to control flood successfully fails to control flood successfully because of the climatology factors or climate factors such as temperature state, rainfall, wind movement and the natural condition of the earth (Balek, 1983). These normally take place on the East Coast throughout the monsoon season. Moreover, elements such as unrestrained development, indiscriminate land clearance as well as other human activities have also amplified the severity of flood (Rahman, 2014).

Vulnerability is one of the best indicators to exhibit the seriousness of flood prone areas and is the central element in the flood risk assessment and damage evaluation (Huang et al., 2012). In general, vulnerability is defined as the potency of being affected by a disaster loss, hazard and exposure (Messner and Meyer, 2006). Vulnerability assessment has been conducted commonly in most developed countries, still, in Malaysia, there is a lacking in the vulnerability measurement in a flood area (Akukwe and Ogbodo, 2015). Even though a region may be identified as seriously affected by flood, however, there is lack in the appropriate measurement system to determine how severe the location is affected. Remote sensing and geographic information system (GIS) are the visualization tools which are commonly used for vulnerability assessment. In the meantime, the present quantitative methods are very sensitive to weights set for sub-indices which point to less convincing analytic results (Huang et al., 2012). Alternatively, Data Envelopment Analysis (DEA) is used by a few studies in an effort to improve present analytical method. The central aims of this study are to determine the degree of vulnerability of each district in Kelantan to flood disaster as well as to compare the dissimilarities in terms of flood vulnerability measures based on ten districts in Kelantan.

METHODOLOGY

Data Envelopment Analysis (DEA) is an efficiency assessment model that uses linear programming to compute an efficiency score for each decision making unit (Charnes et al., 1978). In a vulnerability evaluation, the event of disaster loss denotes the product of interactions within the natural disaster system where it is seen as an "input-output" system (Huang et al., 2012). In general, the production efficiency of loss caused by flood disasters reflects the vulnerability to flood hazards. For instance, a region with low vulnerability, will undergo less severe damage. Normally, DEA model is used to evaluate the relative efficiency of real-bodied producing sectors such as factories, but, in this study, the efficiency score is used to reflect the vulnerability score to flood disaster by 10 basic assessment units. 10 Kelantan's districts are selected as decision-making units (DMUs, in the DEA) involving seven year period starting from 2008 to 2014. Based on the previous study and the availability of the data, this study focus on the dimension of population vulnerability. For each district, the selected input is the population density and the selected outputs are the number of flood victims and the infrastructure damage of Department of Irrigation and Drainage (DID). The data source are from the Department of Statistics Malaysia (DOSM), Department of Social Welfare and Department of Irrigation and Drainage (DID).

Table 1: List of input and output of DEA analysis

Dimension	Variables		Description
Population Vulnerability	Input	Population Density	Average number of individuals in a population per unit area
	Output	Number of flood victims	Number of flood victims being reported in each Kelantan's district.
		Infrastructure damage due to flood	Infrastructure loss due to flood of DID in Malaysian Ringgit (MYR) for each Kelantan's district.

Efficiency Measurement System (EMS) program software is used to implement DEA models in order to determine the population vulnerability. The greater the efficiency score is, the more severe the disaster is (Liu et al, 2010). Assume that the variable x_1 and variable set (y_1 and y_2) represent input-output, respectively. Population vulnerability can be expressed as:

$$\text{Efficiency} = \frac{\sum_{r=1}^{2} u_r * y_r}{\sum_{i=1}^{1} v_i * x_i} \tag{1}$$

where u_r means the weight attached for output r, v_i means the weight attached for input i, y_r is the quantity of output r and x_i is the quantity of input i. x_1: population density of Kelantan's district, y_1: number of flood victims, y_2: infrastructure damage due to flood.

In this study, the population vulnerability is developed based on the Constant Returns to Scale (CRS) model of DEA. The model is as follows:

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

where θ is the efficiency index, x is the input variables, y is the output variables, n is the number of DMUs, λ_j is the weight, s^+ is output slacks and s^- is input slacks. An example is given in order to aid the understanding of the assessment model of the population vulnerability of flood disaster. There are one input (x_{1n}) and two outputs (y_{1n}, y_{2n}) in the model of population vulnerability for each district. For instance, a district with n = 1, the input is x_{11} and the outputs are y_{11} and y_{12}. The Eq. (2) is rewrite as follows:

Min $\boldsymbol{V}$

subject to

$$
\begin{aligned}
&-y_{11} + (y_{11}\lambda_1 + y_{12}\lambda_2 + y_{13}\lambda_3 + ... + y_{1n}\lambda_n) \geq 0, \\
&-y_{21} + (y_{21}\lambda_1 + y_{22}\lambda_2 + y_{23}\lambda_3 + ... + y_{2n}\lambda_n) \geq 0, \\
&\theta x_{11} + (x_{11}\lambda_1 + x_{12}\lambda_2 + x_{13}\lambda_3 + ... + x_{1n}\lambda_n) \geq 0, \\
&\lambda \geq 0,
\end{aligned} \tag{3}
$$

where n = 10 and $\lambda = (\lambda_1, \lambda_2, \lambda_3, ..., \lambda_n)$. Using Eq. (3), the minimum value for $\boldsymbol{V}$ is calculated. For this example, the $\boldsymbol{V}$ value is the population vulnerability of flood disaster in the Kelantan's district with n = 1. If the value of $\boldsymbol{V}$ closer and approximates to 1, the population vulnerability of the flood disaster will become higher and vice versa. Thus, if the value of $\boldsymbol{V}$ is equal to one, the district is said to have the highest population vulnerability.

DISTRICT ANALYSIS OF THE POPULATION VULNERABILITY BY FLOOD DISASTER IN KELANTAN

The objective of this study is to determine the degree of severity of flood disaster for each district of Kelantan based on DEA analysis. A time series DEA analysis has been implemented to determine the population vulnerability in the state of Kelantan for the period of 2008 to 2014. A district with index of 1.0 indicates the highest population vulnerability; that is to say, the district was the most affected district by flood disaster. The results from the DEA analysis are presented in Table 2.

From Table 2, we can see the yearly population vulnerability of flood disaster in Kelantan. For instance, taking the following details for the year 2008: (1) The most affected Kelantan's district by flood disaster for population vulnerability were Jeli and Kuala Krai; their index of population vulnerability are equal to 1.0. (2) The least affected district by flood disaster for population vulnerability was Bachok; its index of population vulnerability is 0.387. (3) Generally, the districts in the central of Kelantan's state were highly vulnerable. For example, the vulnerability index of Pasir Mas was 0.794, Pasir Puteh region was 0.712 and the corresponding index for Machang was 0.625. Table 3 lists the most affected Kelantan's district by flood disaster for population vulnerability in each year starting 2008 to 2014. Each of the Kelantan's district corresponds to the index of 1.0 in the corresponding year.

Table 2: Population vulnerability index of flood disaster in Kelantan's district, 2008-2014

	2008	2009	2010	2011	2012	2013	2014
Bachok	0.387	0.526	0.511	0.528	0.339	0.500	0.558
Gua Musang	0.500	0.500	0.500	1.000	0.500	0.500	1.000
Jeli	1.000	0.564	0.500	0.475	0.851	1.000	0.930
Kota Bharu	0.534	0.341	0.523	0.578	0.341	0.347	0.636
Kuala Krai	1.000	1.000	0.564	1.000	1.000	0.784	1.000
Machang	0.625	1.000	0.500	0.385	1.000	1.000	1.000
Pasir Mas	0.794	1.000	1.000	1.000	1.000	1.000	0.639
Pasir Puteh	0.712	0.537	0.810	0.587	0.387	0.824	0.587
Tanah Merah	0.596	0.595	0.528	0.586	0.620	0.593	0.785
Tumpat	0.592	0.807	1.000	1.000	0.807	0.584	0.611

Based on Table 3, there were 6 districts which scored an index of population vulnerability by flood disaster of 1.0 throughout the 7 years and this show that the flood disaster occurred randomly in terms of spatial distribution. Bachok, Pasir Puteh, Tanah Merah and Kota Bharu never once appear in Table 3; alternatively stated, population in these districts were not the most prone to flood disaster from the year 2008 to 2014. The remaining six districts appear in Table 3 more than once; that is, the population in these districts were greatly vulnerable to flood disaster. Figure 1 shows a scatter plot of districts where population is most vulnerable to flood disaster; that is when the population vulnerability index is equal to one.

Table 3: The most vulnerable district from 2008 to 2014 (population vulnerability index = 1)

Year	DMU
2008	Jeli, Kuala Krai
2009	Kuala Krai, Machang, Pasir Mas
2010	Pasir Mas, Tumpat,
2011	Gua Musang, Kuala Krai, Pasir Mas, Tumpat
2012	Kuala Krai, Machang, Pasir Mas
2013	Jeli, Machang, Pasir Mas
2014	Gua Musang, Kuala Krai, Machang

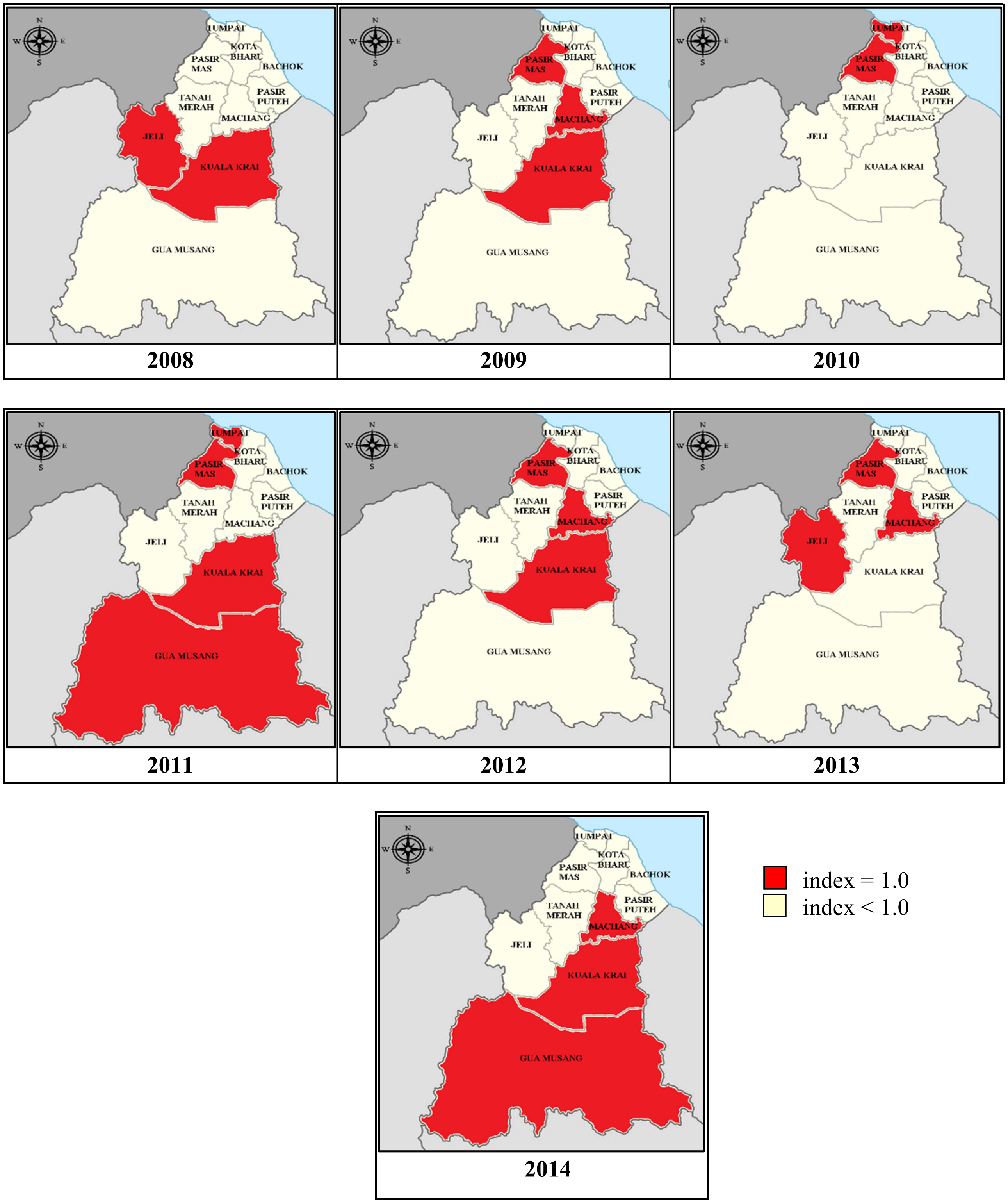

Figure 1: Districts with population vulnerability index equal to 1 from year 2008 to 2014

Table 4 shows the number of event of 1.0 population vulnerability index for the relative district through the seven years. Kuala Krai and Pasir Mas were the most often to be the most vulnerable region, which is five occurrences across the seven years, followed by Machang, four occurrences and Gua Musang, Jeli and Tumpat with two occurrences each.

Table 4: List of DMUs with vulnerability index of one occur more than once from 2008 to 2014

DMU	Number of vulnerability index = 1.0
Gua Musang	2
Jeli	2
Kuala Krai	5
Machang	4
Pasir Mas	5
Tumpat	2

CONCLUSION

This study concentrates on one dimension of vulnerability assessment only which is population vulnerability of each Kelantan's district for the period of 2008 to 2014. From the outcomes, it can be shown that Kuala Krai and Pasir Mas are the most vulnerable to flood among the ten districts. Other dimensional flood vulnerability assessment should be conducted for instance, economic vulnerability, industry vulnerability, and transportation vulnerability in order to contribute to a deeper understanding of the flood vulnerability in Malaysia. It is more effective to assess flood vulnerability in various dimensions since it is more difficult and complex to consider all criteria in only one model of the DEA method. Plus, the same input may speak out different impact on different type of disaster loss.

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