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ESTABLISHMENT OF RESIDENTIAL FLOOD DAMAGE FUNCTION MODEL FOR KUANTAN, MALAYSIA

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ABSTRACT: Flood damage estimation is an essential element in the assessment of flood risk. However, the study on flood damage in developing countries is limited due to the scarcity of historical data. An attempt has been made to derive residential flood damage function models and flood depth-damage curve for the year 2013 flood in Kuantan, in the state of Pahang in Malaysia. A field survey was conducted to gather information regarding the flood event based on face to face interview technique. The education background, household income, and construction materials had a significant influence on the variation of structural flood damages, whereas the content damage was found to be depended mostly on the types of occupation, household income, and house type. The flood depth-damage curves obtained in this study are satisfactory as content and structural damage shows R^2 above 0.80 for both and can be used for future studies on flood damage assessment of the study area.

Keywords: Flood damage estimation

1. INTRODUCTION

Flood risk assessment consists of two main parts i.e. a hazard and vulnerability assessment. Flood hazard is normally illustrated in flood inundation or flood extend maps, while flood vulnerability emphasizes the impact of flooding in flood damage map. Flood vulnerability is associated with the assessment of flood damages. Estimation of economic loss is essential to help the development of new housing away from the flood disaster area and reduce the damage loss.

The assessment of flood damages can be done using two methods; either evaluated directly from existing database or by using modeling approach. The modeling of damage estimates is either using a unit loss model or a model that relates the flood damages with other factors that have a linkage effect on the damages such as economic factor, the nature of the damage, and possible relations between damage and flood parameters [1]. The unit loss method is defined as a property-by-property assessment of potential damage [1] and it uses the relationship between flood characteristics and damages to a unit [2]. In the latter method, three well-known flood damage estimation models are FDAP (Flood Damage Analysis Package), ANUFLOOD and ESTDAM. Although various different approaches had been used to estimate flood damages, the estimation concept is basically the same, which considers the combination of flood hazard (hydrological characteristics), exposure, value of elements at risk, and the susceptibility of the elements at risk to particular hydrologic conditions which can be represented by a flood damage function curve [3]-[5].

Flood damage function curve is the plot of flood damages to flood parameters [6]. It shows the relationship between the flood parameters with the level of flood damage [7]. Examples of commonly used flood damage influencing factors for flood damage functions are flood depth, flood duration and velocity [1]. However, according to Thieken et al. [8], damage influencing factors consist of two types i.e. the impact parameters and the resistance parameters. The impact parameters reflect the specific characteristics of a flood event such as water depth and flow velocity, while resistance parameters represent the properties of the affected assets such as building type or materials and the emergency measures used.

Flood damage curve can be derived using two methods depending on the availability of the data. The first is based on damage data of past floods or also known as empirical method, and the second is termed as synthetic method, which is based on hypothetical analysis [1]. The curve based on empirical method, or also known as historical curve [10] is derived from historical loss data of actual flood events. While in the latter method, the development of synthetic flood damage function curve does not rely on the actual flood damage information, but derived from hypothetical analysis based on land cover and land use patterns, type of objects, information from questionnaire survey, interviews and expert judgements [1], [11], [12]. This synthetic method had been adopted by researchers who experienced a data scarcity problem [10], [11].

Although the first research on flood damage assessment field can be traced back almost forty years ago, there is still a lot of works to do related to few issues. In developing countries, especially Malaysia, the study on flood vulnerability assessment is still limited especially on flood damage estimation. There are many methodologies for estimating the flood damage worldwide. However, there is no common methodology applied to estimate flood damage in Malaysia. The effect of resistance parameters on the degree of flood damages is usually neglected in damage modeling, as most studies select more influencing parameters such as flood depth. Flood risk assessment should cover all damage dimensions to obtain an extensive description of flood damages [13]. Therefore, with the aim to assist in the assessment of flood vulnerability, the purpose of this study is to investigate the relationship between flood damages and the local condition of the study area and to establish a residential flood depth-damage curve for future flood risk assessment works in Kuantan.

2. METHODS

2.1 Case Study Area

The Kuantan River Basin (KRB) was selected as the location for this case study because it is known for its frequent flooding. KRB has a catchment area of 1638 km^2 and the length of the river is approximately 93.44 km. Kuantan River is the main river in KRB where it flows from Mukim Ulu Kuantan through the Kuantan city and ends at the Perkampungan Tanjung Lumpur before flowing out to South China Sea.

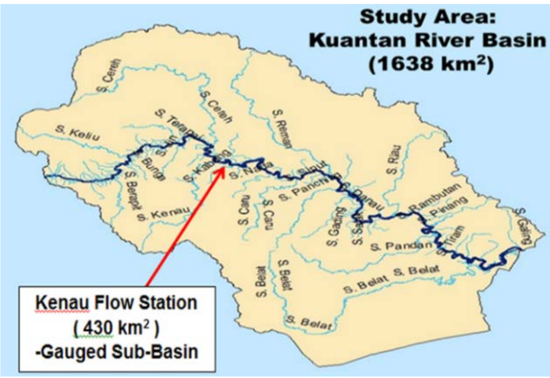

Fig. 1 Location of the study area

In the last few decades, the Kuantan River has experienced severe floods in 2001/02, 2011/12, and recently in 2013. There were major damages to properties, infrastructures and traffic, while around 14,044 people were evacuated during the 2013 flood [14]. The map of KRB displays the area, main river, tributaries and the streamflow station which is Kenau Flow Station is shown in Fig. 1 [15].

A few flood risk studies had been done [16]-[18] for flood mitigation at Kuantan River. However, to date, none flood vulnerability assessment has been studied within the river basin. Hence, a study on the assessment of flood damage is compelling to assess the impacts of flood to properties and the society of Kuantan.

2.2 Questionnaire and Field Survey

A field survey using face to face interview technique was conducted to gain a clearer picture of the 2013 Kuantan flood. A questionnaire was developed and distributed among the flood-affected residence twice, with the initial survey was conducted in March 2018 and the second survey being conducted in February 2019.

The questionnaire was designed according to three scopes; demographic data, information on residential property and damage data. There are two sections; Section 1 and Section 2. Demographic and residential property were considered in Section 1, while Section 2 gathered information on the damage experienced by residents during the 2013 flood. Under demographic, various factors, such as gender, age, race, education level, occupation, and household income data were collected, whereas the price of the house, year bought, ownership status, house's type, numbers of storeys, house's material, house's insurance, and the estimated price of the house contents (furniture, gate, etc.) were investigated under the residential property scope. To gain information on damage, the flood depth and duration were considered, as well as the cost of damage to fabric/structural, cleaning, content damage, vehicle damage and loss of wages.

This survey used randomly selected sampling in the flood-prone area of Kuantan to collect a representative sample, as suggested by Win et al. [19]. Information about the flood prone areas was collected from Drainage and Irrigation Department (DID) Kuantan, Kuantan Municipal Council and available flood maps. By using this information, a few 2013 flood-affected villages in Kuantan area were selected for the survey i.e. Permatang Badak, Sungai Isap, Bukit Rangin, Bukit Setongkol, Kampung Sungai Soi and Kampung Galing Besar. In each village, interviews were conducted randomly at different location and end up with a total of 201 samples.

2.3 Multiple Regression Analysis

A multiple regression model was used in this study to model the relationship between flood and various flood damage influencing variables. This method had been adopted by several previous researchers to analyze flood damage and its determinants [19]-[21].

In this study, every value of the independent variable (flood influenced factor, *x*) is associated with the value of the dependent variable (flood damages, $Flood_D$). The dependent variable covers the level of property damages in terms of structural and content damage. While the independent variables are divided into two categories i.e. demographic and property characteristics. The demographic variables are gender, age, race, education background, occupation and house income, whereas the properties variables are ownership, price of properties, property type, number of storeys, building material, and flood insurance status. The general regression equation is as Eq. (1) below:

$$Flood_D = f(x_{i1}, x_{i2}, x_{i3}............+ x_{ip}) \quad (1)$$

The transformation of the functions for model in Eq. (1) resulted in a regression model as shown in Eq. (2):

$$lnFlood_{Di} = \beta_0 + \beta_1 lnx_{i1} + \beta_2 lnx_{i2} + \cdots + \beta_p x_{ip} + \varepsilon_i \quad (2)$$

Where $i = 1, 2, 3, ...n$ while p and ε refer to the numbers of independent variables and error term respectively. *lnFlood* is the logarithm of flood damages from surveys.

The analysis observed the value of coefficient of determination (R^2) and p-value (significance level), where a 5% significance level ($p < 0.05$) is used.

2.4 Flood Depth-Damage Curve

Flood damage function curve is the relationship between flood damages (in percentages) against flood parameters. The level of damage was measured according to flood depth and was taken as the ratio of the overall replacement cost to the estimated total replacement value of the building. The damage percentage (D_p) was calculated according to the definition by Pistrika et al. (2014) as in Eq. (3):

$$D_p = \frac{\text{Overall Replacement Cost}}{\text{Market Value of Properties}} \times 100 \quad (3)$$

The overall replacement is the expenses spent by the flood victim to mend their properties after flood, either at their own cost or compensation from the government or insurance company. The damage replacement was estimated for the structural, content, stock and equipment damage. The flood parameter chosen in the establishment of the damage curve is flood depth. Based on previous published work, inundation depth is considered as the principal factor and found to be the major variable for assessing direct tangible damages [1], [7], [22]. Furthermore, Chang et al. [23] suggested that the flood depth alone is sufficient for flood damage estimation without considering other factors.

The curve is plotted using Microsoft Excel and the curve fitting process was performed using trial and error. Curve fitting is the process of constructing a mathematical function that best fits a series of data points [12]. The logarithmic trend line was selected as the type of trend line best fitted the data and the curve shape is similar to other damage curves from previous studies [1], [12], [14]. The average value of flood depth and percentages of damage was used in the construction of the damage curve.

3. RESULTS AND DISCUSSION

3.1 Survey Results

The field survey data collection yielded a wide range of useful parameters that may help in the assessment of flood damage [19]. Based on the primary collected data, more than 54% of the respondent were male while the rest were female. The average age of the respondents was 45 years old.

The house type that is mostly observed in Kuantan area is brick since 62% of the house interviewed during the survey is brick wall house. Further, 29% of the houses are built as the combination of brick and timber materials, whereas wooden houses are observed to be only 9% of the survey samples.

Most of the house sample was terrace (69%), while only 6% was semi-detached house, 9% was bungalow and 16% was other than these house types. Almost 97% of the house was one storey house.

3.2 Flood Damage Function Models

3.2.1 Structural Damage Functions

The relationship between structural damage and demographic and property variables is explained by Eq. (4) with the regression results shown in Table 1. The R^2 obtained is low i.e. 0.19. However, the value is acceptable for cross-sectional data and it is in agreement with the result observed in Poussin et al. [25] which relate the flood damage mitigation behavior amongst households in France where the R^2 was between 0.19 to 0.31.

$$Flood_{struc} = -10974 - 1422EDU + 1799 \ln INC + 1066MAT + \varepsilon \quad (4)$$

where ε is error term and $Flood_{struc}$ is the structural flood damage in RM (Ringgit Malaysia) with the following influenced factors;

EDU	=	Education level of the respondent
INC	=	Household income of the respondents
MAT	=	Construction material of the houses

Table 1 Regression analysis results on the impact of demographic and property variables on structural flood damages

Variable	Coeffi-cient	Std. Error	t	p-value
EDU	-1421	467.24	-3.04	0.003
lnINC	1799	368.92	4.88	0.000
MAT	1066	458.44	2.33	0.021
Constant	-10974	2803	-3.92	0.000

The results in Table 1 show that the value of residential structural damage is positively correlated with the house material and household income but is negatively correlated with the respondents' education background. Assuming that all other variables are unchanged, a unit increment in household income will result in RM1799 increment in the structural damage when a linear relationship is assumed. These define the affordability of the high income respondent in buying a more expensive house or wall furnishing, gate, etc., thus cause greater damage.

Meanwhile, the structural damage decrease by RM1421 if the respondent's educational background is at higher level. This result is consistent with Panic et al. [26] and Morrisey [27] who found that education also plays a crucial role in influencing the flood damage. The people with a better educational background is more knowledgeable, hence tend to be more aware and prepared for any natural disaster event [20]. Based on the observation from survey, most of the residents with high education level works at private sector or owns a business. Similarly, people with better occupation tend to be more exposed with advance mitigation options and well prepared. On the other hand, the damage increased by RM1066 if the house is built from concrete. This is in agreement with the finding by Win et al. [19] who stated that the rate of flood damage is commonly related to the total household, household income, and building materials variables.

3.2.2 Content Damage Functions

The R^2 value is 0.19 which is similar to the structural damage model. The results for content damage are summarized in Eq. (5) and Table 2.

$$Flood_{content} = -4040 + 3157OCCU + 1586 \ln INC - 3396 \ln TYPE + \varepsilon \quad (5)$$

where ε is error term and $Flood_{content}$ is the content flood damage in RM with the following influenced factors;

OCCU	=	Occupation of the respondents
lnINC	=	Household income of the respondents
TYPE	=	Types of the houses

Table 2 Regression analysis results on the impact of demographic and property variables on structural content flood damages

Variable	Coeffi-cient	Std. Error	t	p-value
OCCU	3157	1251	2.52	0.012
lnINC	1586	651	2.44	0.016
TYPE	-3396	858	-3.96	0.000
Constant	-4040	5143	-0.79	0.433

The occupation and household income were found to have significant positive relationships with the total amount of content damage. However, the content damage is negatively related to house type. Assuming that all other variables are unchanged, a unit increment in household income will result in RM1586 increment in the structural damage when a linear relationship is assumed. The content damage increases by RM3157 if the respondent is a businessperson. Respondents with better occupation may own a high quality and expensive furniture thus experienced high damage if their house content is affected by flood. The content damage decreases by RM3396 for the terrace house. This can be justified by the content of the terrace house may be cheaper than the content damage of semi-detached house or bungalow.

3.3 Flood Depth-Damage Curves

The flood depth-damage curve for structural and content damage is shown in Fig. 2 and Fig. 3 respectively. Both graphs show a significant correlation, where the percentages of damage increase with the flood depth, with R^2 values of more than 0.8 for all categories. This is in agreement with Pistrika et al. [12] for residential area, R^2 of 0.78.

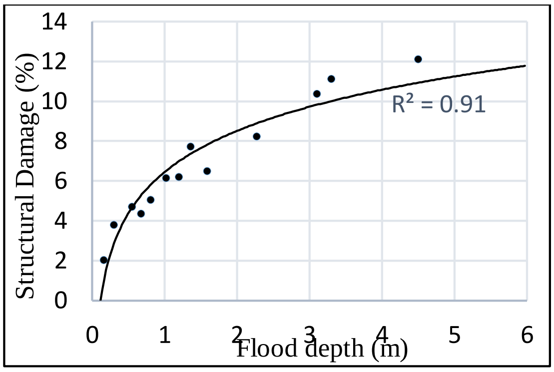

Fig. 2 Residential flood depth-damage curve for structural damage

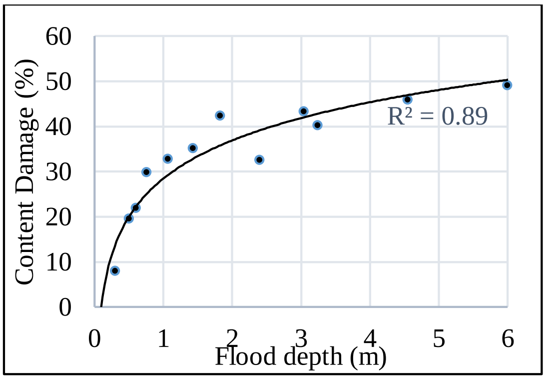

Fig. 3 Residential flood depth-damage curve for content damage

The result shows that the 2013 flood victims experienced content damage higher than structural damage. Content damage estimates as high as 50% are expected at 6 meters' flood level, compared to 12% for structural damage. The finding is consistent with the observation by Pistrika et al. [12] in Greece where all the flood-affected buildings required only minor repair.

The percentages of content damage are quite low which is between 2% to 12% for a flood depth up to 6 meters. The study by Pistrika et al. [12] obtained a similar low percentage damage, range from 9% to 18% also for up to 6 meters inundation depth.

4. CONCLUSION

Flood damage function model was developed based on interview survey data. The model considered the effects of demographic and property characteristics variables on the level of flood damages.

From this study, the structural damage was found to be depended mostly on the education background, household income, and construction materials, whereas the content damage was found to be depended mostly on the types of occupation, household income, and house type.

Flood depth-damage curves show that the residents of Kuantan River Basin experienced content damage more than the structural damage during the 2013 flood. For the flood depth up to 6 meters, the percentages of content damage are in between 9% to 50% while the structural damage is in the range 2% to 12%. The damage curves obtained in this study are good enough with R^2 0.91 and 0.89 for structural and content damage respectively and can be applied in future flood damage assessment works at the study area.

Some recommendations for the future flood damage assessment works are derived. An additional data collection is suggested to improve the flood damage function model, in terms of the coefficient of determination (R^2). Besides a damage assessment for residential category, future works should also include commercial and industrial categories. These categories are rarely investigated as getting reliable damage data for the commercial and industrial category is expected to be more challenging. However, the damage assessment of these categories is compelling as it may show the effect of urbanization to the study area.

5. ACKNOWLEDGMENTS

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