FLOOD RISK ASSESSMENT: A REVIEW OF FLOOD DAMAGE ESTIMATION MODEL FOR MALAYSIA

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Graphical abstract
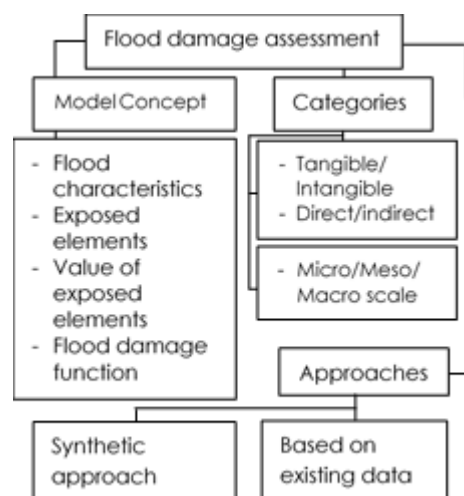
Abstract

Flood damage assessment is important in flood risk management for the assessment of flood vulnerability, development of flood risk map and flood management financial appraisal. In Malaysia, there is a lack of studies on flood damages estimation. In addition, the needed data for the assessment of flood damages is scarce. This review identified the approaches and problems in flood damage assessment. For Malaysia, the combination of four elements namely; flood characteristics (flood depth and flood duration), characteristic of exposed elements, value of exposed element and flood damage function curve are recommended. The scarcity of data for developing flood damage curve could partly be overcome by applying synthetic method to generate additional data from the existing flood damage data.

Keywords: Flood risk assessment, flood damage assessment, flood damage function curve, synthetic method, developing country

Abstrak

Anggaran kerosakan akibat banjir adalah penting dalam pengurusan risiko banjir, iaitu bagi tujuan mengukur tahap keterdedahan terhadap banjir, pembangunan peta risiko banjir dan penilaian peruntukan pengurusan banjir. Di Malaysia, kajian penganggaran kerosakan akibat banjir adalah sangat sedikit. Selain itu, data yang diperlukan untuk menilai kerosakan banjir juga sangat terhad. Manuskrip ini mengenalpasti pendekatan dan masalah dalam melakukan penganggaran kerosakan akibat banjir. Berdasarkan penelitian yang dibuat, disyorkan bahawa gabungan empat unsur iaitu; ciri-ciri banjir (aras banjir dan tempoh banjir), ciri-ciri dan nilai elemen terdedah kepada banjir, dan lengkung kerosakan banjir digunakan dalam permodelan anggaran kerosakan banjir untuk kajian kes di Malaysia. Keterbatasan data untuk membina lengkung kerosakan banjir boleh dikurangkan dengan penjanaan data secara sintetik dari data sedia ada.

Kata kunci: Penilaian risiko banjir, anggaran kerosakan banjir, lengkung kerosakan banjir, kaedah sintetik, negara membangun

1.0 INTRODUCTION

Flood is one of natural disasters that causes great harm to human being, causing major damage to properties and impact severely on socio-economic activities [3]. Even worse, flood may also lead to losses of human life and decreases the quality of human health [4]. It is believed that flood disaster had caused about 100,000 deaths and affected 1.4 billion people worldwide during the end of 20th century [4]. In Malaysia, flood occurs frequently with average annual physical damage of 915 million and affecting almost 29,800 km^2 area and 4.82 million people [5, 6]. The figures tend to increase nowadays as the occurrence of large floods is expected to increase periodically [1] as the result of the climate change phenomenon [2]. Unless sustainable flood management plan is in place, flood will affect more population and at greater socio-economic and environmental losses [7, 8]. Furthermore, more flood events tend to occur abruptly due widespread land developments and more intense rainfall [9]. In an attempts to deal with this problems, various efforts have been done by engineers, researchers and policy makers to minimize the risk of flooding i.e. by constructing flood mitigation structures such as detention dam, dyke, and levees [10]. On the other hand, the implementation of non-structural measures such as flood mapping, flood modeling and flood forecasting are equally important flood mitigation options [11].

In recent years, a risk-based flood mitigation concept has received more attention compared to the conventional flood control approach that give much focus on structural flood mitigation measures [12, 13, 14]. For example, in the end of 2007, countries in Europe had adopted a flood risk management concept that led to a requirement for each member country to carry out flood hazard and risk map to support their flood risk management plans [15]. In Malaysia, the management and implementation of flood control measure is under the jurisdiction of the Department of Irrigation and Drainage (DID). In the current practice, the mitigation works put a lot of emphasis on structural measures [16], as compared to non-structural measures [17]. The laws and regulations regarding the flood management in Malaysia is inadequate [18] especially in the management of flood risk where the approach is still new and lack of legislative framework [9].

Flood damage assessment is crucial in flood risk management and is an important element for the flood risk vulnerability assessment i.e. in the development of flood risk mapping, risk analysis comparison and financial appraisals for budget allocation during and after flood disaster [11] and also in cost benefit analysis (CBA) such as in financial judgement for flood mitigation measures [19, 20]. CBA is a useful decision making tool in choosing the appropriate flood control options and to evaluate the effectiveness of the selected options [15]. Flood damage estimation is also crucial in insurance sector, in order to estimate potential losses and insurance pricing [12]. Flood characteristics, such as the expected water level for the respective annual recurrence interval (ARI) and flood damage function curve are the elements in flood damage estimates that are needed for flood insurance pricing [21].

Quite huge body of literatures have been published on flood risk and damage estimation [e.g. 14, 19, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33]. However, most of the works are from developed countries and still very few from developing countries including Malaysia. To date, the published information on this subject are those by Muradi and Abdullah [34], Tam *et al*. [35], Ahamad [36], and KTA Tenaga Sdn Bhd [37]. Unfortunately, most of the studies have adopted methodologies from developed countries which have limited applicability in the Malaysian context [38].

Among challenges in conducting flood damage assessment studies in a developing country are the scarcity of flood damage data and limited access to related information [39, 40]. For a developing country like Malaysia which is still at the early stage of adopting the flood risk management practice, having a flood damage assessment framework that reflects her own scenario of flood and socio-economic conditions is crucial for a better flood management system. This manuscript presents a general overview on the following issues; types of flood damages, elements considered in the flood damage estimation approaches, methodology adopted, and problems in the assessment of flood damages. The focus is limited to tangible direct flood damage assessment. At the end, a recommendation for the development of flood damage estimation model for Malaysia is proposed.

2.0 FLOOD RISK ASSESSMENT

Flood risk basically revolved around two main elements; hazard and vulnerability [14, 15, 29, 41]. The risk is generally defined as the probability of a flood event to occur (hazard) and the potential of flooding impacts to the community and assets (vulnerability) [41, 43]. In economic circumstances, expected annual damage is commonly used to represent flood risk [14] which can be obtained by the multiplication of flood hazard (probability of an event) with the flood vulnerability (flood damage) [12, 15, 44].

The flood extent and magnitude are the flood variables that are usually used for the assessment of hazard, whereas the vulnerability part assesses the potential consequences of the flooding to the exposed elements such as properties, human beings, goods, and environment [15, 42, 45]. The vulnerability assessment is normally associated with the assessment of property damages [41].

According to Apel *et al*. [46] in their attempt to develop a probabilistic modelling system for the assessment of flood risks in river Rhine, Germany, hazard alone is not enough for developing a flood defence system. Hence, a more comprehensive risk-based design that takes into consideration the flood hazard and the consequences of flooding is preferred. Besides hazard and vulnerability, another element that has been given attention in the recent risk assessment measures is exposure. The term exposure refers to "the presence of people, livelihoods, environmental services and resources, infrastructure or economic, social or cultural assets in places that could be adversely affected" [47]. De Moel and Aerts [13] and Gain *et al*. [47] in their flood risk assessment study in Netherlands and the city of Dhaka respectively, considered the elements of hazard, exposure and vulnerability, where the combination of these provides a better estimate of expected damages related to flood risk.

3.0 FLOOD DAMAGE ESTIMATION MODEL

3.1 Classification of Flood Damages

Flood damages can be generally divided into two main types; tangible and intangible damages [26, 32, 48]. Tangible damage is the damage that can be measured directly in monetary term [23] while intangible damage is not. Intangible damage such as losses of ecosystem functions is difficult to translate because the monetary value is not readily assessed [11]. Flood damages can also be experienced in a direct or indirect way [45]. Hence, the tangible and intangible damage can be further divided into two sub types, i.e. direct and indirect damage. Direct damages are the damage that occurred due to the physical contact of flood water with humans, property or any other asset [12], such as building and inventory items [48]. The indirect damage is the damage that is induced by the flood impacts and occurs in space and time, outside the flooded area [12]. Some illustrations of indirect damage are the interruption of traffic flows, income loss, and losses due to business shut down [48]. More examples of different types of damage are listed in Table 1.

In addition, flood damages can be classified into three levels; micro-scale, meso-scale, and macro-scale (Table 2). The classification into micro-, meso- and macro-scale is related to the spatial extent of damage assessment [12], the size of study area and differentiation of land use categories [31, 49, 50].

In general, flood damage can be estimated based on land use as the degree of damages varies with different types of land use, though the flood characteristics, such as flood depth and peak flow are the same [48]. Based on this, damage can be categorized into residential, commercial, industrial, agricultural and infrastructure. Meanwhile, different economic sectors may contribute to different levels of flood damage due to different characteristics concerning assets and susceptibility [12]. Hence the assessment of flood damage can also be classified according to different types of business/company, private households and infrastructure [12].

Table 1 Types of flood damages (adapted from [12, 26])

	Tangible	Intangible
Direct	Building and contents damage, infrastructure damage (e.g. roads), agricultural soil erosion, harvest destruction; livestock damage, evacuation and rescue measures, business interruption, clean-up costs, land and environment recovery.	Loss of life, injuries, psychological distress, cultural heritage damage, negative effects on ecosystems.
Indirect	Public services interruption (e.g. communication system), induced production losses to companies outside the flooded area (e.g. suppliers of flooded companies), traffic disruption cost, tax revenue loss due to migration of companies in the aftermath of flood, business interruption.	Trauma, loss of trust in authorities and health and psychological damage.

Table 2 Classes of flood damages (adapted from [12, 31])

Micro-scale	- Single exposed elements assessment - Local studies analysis (use a per building approach)
Meso-scale	- Spatial aggregations assessment - Regional studies analysis (consider aggregated land use units)
Macro-scale	- Large-scale spatial units assessment - National and/or international studies analysis

3.2 The Flood Damage Assessment Concept

Flood damage assessment is generally based on two approaches. In the first approach, flood damage is evaluated from existing flood damage data base, collected from interview survey or from secondary sources such as local authorities, newspaper, and internet [e.g. 51, 52]. The second approach of damage estimation uses model that relates the flood damages with other related factors such as economic, the nature of damage, and flood variables [19, 26, 48]. Penning-Rowsell and Chatterton [22], Smith [53] and UNSW [54] are examples of studies that had successfully established detailed methodologies of tangible flood damage estimation in the United Kingdom and Australia respectively [26].

Although various different approaches had been used to estimate flood damages, the estimation concept is basically the same, which consider the economic value of the element at risk, together with the hydrological characteristics [49, 13]. In summary, the necessary elements are 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. The combination of these four elements are needed in the development of flood risk/damage assessment works.

In evaluating the adopted approaches and elements considered in flood damage estimation model, a total of 25 articles were reviewed and summarized in Table 3. The selection of the articles was limited to ISI and Scopus indexed journals. Out of 25 articles reviewed, 71% are from developed countries especially Netherlands, Japan, and Italy. It was found that 83.3% of the studies employed the similar concept outlined by Meyer and Messner [49] and De Moel and Aerts [13], where the combination of flood hazard, exposure, value of elements at risk, and flood damage function curve were applied. For example, Ward *et al*. [14] used the combination of flood hazard, characteristics and the value of exposed assets, and information about the susceptibility of exposed assets to a particular hazard to estimate expected annual damage in their study.In addition, the damage estimates consider the same elements, although the components, methods and techniques used are difference. For example, in flood hazard analysis, some studies applied hydrologic-hydraulic modeling [e.g. 19, 55] while other studies obtain flood characteristics information from secondary data [e.g. 29, 56, 32].

In summary, the elaborated concept had been successfully used by many researchers to assess flood damage in various countries, either in developed or developing countries.

3.3 Hydrological Characteristics

Flood depth and flood extent are two variables needed in the estimation of flood damages [13, 19]. These can be obtained from a probabilistic or deterministic analysis in a flood hazard model [57]. Thus far, numerous flood models have been used in flood damage estimation studies to provide the total extend of flooded area and to identify the spatial distribution of flood depth [19].

Delft Hydraulics Institute has developed a flood hazard assessment model (FHAM) to quantify the consequences of flooding, which focus on the socio-economic impact [55]. Within the flood hazard assessment model, a flood model is used to calculate the extent of flooding while a damage assessment model calculates the expected yearly damage. The GIS based flood model is a one-dimensional hydraulic model of a river. The calculated flood depths serve as the input to the damage assessment model.

Dutta *et al*. [26] developed a physically based distributed hydrologic model to simulate flood inundation parameters as part of their flood loss estimation model. The hydrologic model [53] considers five major processes of hydrologic cycle, which are interception and evapotranspiration, river flow, overland flow, unsaturated zone flow and saturated zone flow. The model introduced by Dutta *et al*. [26] is an integrated model combining a flood inundation simulation and a generalized loss estimation model.

Oliveri and Santoro [19] applied a numerical model that was previously developed by Oliveri *et al*. [59] which used the Saint Venant equation to assess the inundation depth for their flood damage estimation study in the city of Palermo, Italy. The 1D De Saint Venant's equations in conservation law form that was solved by a parabolic approximation for each channel was used in their study. In the model, the urban area was approximated with a network of rectangular channels, representing the streets. The flood simulation provides spatial distribution of the maximum water depths for 50, 100, 300, 500 and 1000 year return periods by interpolating the corresponding maximum water depths using the geostatistical Kriging method.

Ward *et al*. [14] applied a raster based model, Floodscanner to derive inundation maps of the Meuse in Dutch Limburg. The model was developed using zero-dimensioning planar-based approach. The water level at each river grid-cell for different discharges were estimated using a stage-discharge relationship. A planar surface representing the water level per grid-cell was created when the water levels at each river grid-cell are assigned to the nearest non-river grid-cells. The inundation depth is the difference between the cell values of water level and elevation. The outputs from Floodscanner i.e inundation parameters, together with land use map were subsequently used as inputs into the Damagescanner to generate flood damage estimates. Damagescanner is a flood damage model originally developed by De Brujin [60] and used by De Moel *et al*. [61] to assess the uncertainty and sensitivity of coastal flood damage estimation.

In another study by Lekuthai and Vongviseeomjai [48], the MIKE-11 hydrodynamic model was used to generate flood characteristics for estimating damage. The model produced flood depth and duration for every cell, while the flood depth and duration for all areas were derived from topographical map. The values of flood depth and duration were applied in the damage curve equation by Kanchanarat [62]. The damage is then calculated using the direct damage equation proposed by Lekuthai and Vongviseeomjai [48]. Vonizaki *et al*. [33] applied similar flood modeling method using MIKE FLOOD that consists of one-dimensional hydraulic model MIKE 11 and two-dimensional MIKE 21 model. These models were

applied to estimate losses during the Koiliaris basin 2003 flash flood for agricultural category.

Table 3 Summary of adopted approaches and elements considered in flood damage assessment

Authors	Exposed elements (Damage category)	Direct estimation		Flood damage estimation model			
		Secondary data	Interview Survey	Values of exposed element	Flood parameters		Flood damage function
					Hydrologic-hydraulic modeling	Secondary data	
[14]	Residential, commercial, infrastructural, mines/construction, recreation, nature, arable, nature			X	X		X
[19]	Urban			X	X		X
[26]	Urban, rural, infrastructure			X	X		X
[27]	Land use, infrastructure, households, companies, others			X	X		X
[28]	Building (Direct damage)			X	X		X
[29]	Commercial			X		X	X
[32]	Commercial, residential, public building, cultural and historical building			X		X	X
[33]	Agricultural			X	X		X
[34]	Agricultural			X	X		
[35]	Physical element			X	X		X
[36]	Agricultural, residential, industrial			X	X		X
[37]	Urban and rural (agriculture)			X	X		X
[39]	Residential		X	X			X
[48]	Residential, commercial, agricultural, industrial			X	X		X
[51]	Agriculture		X				
[52]	Residential	X					
[55]	Public authorities, private persons, industry, agriculture			X	X		X
[56]	Agricultural, residential, golf courses, traffic zone			X		X	X
[57]	Residential, agricultural, commercial, industrial			X	X		X
[66]	Residential, infrastructure (road), agricultural (winter wheat), industrial			X	X		X
[69]	Agricultural, residential			X	X		X
[45]				X	X		X
[67]	Residential, agricultural, industrial			X	X		X
[71]	Residential, public utility, industrial, agricultural			X	X		X
[72]	Coastal area			X	X		

3.4 Flood Damage Function Curve

The relationship between flood damage to flood parameters in flood damage assessment can be presented by a flood damage function curve. The level of flood damage is influenced by hydrological factors such as flood depth, flood duration, velocity, and frequency of flooding [12, 26]. Thieken *et al*. [63] affirmed that for the case of building and its contents, the rate of damage are also influenced by contamination, along with flood depth and flood duration. Besides hydrological factors, the severity of flood damages is also caused by other factors such as during which time of the year the flooding occur, warning time, sediment load of floodwaters, type of buildings, family income, and the preparedness level before the disaster [3].

Flood depth is the most commonly used parameters in flood damage function curve. According to Notaro *et al*. [8], inundation depth is considered as the principle factor for assessing direct tangible damages. Shaw *et al*. [64] also found flood depth as the major variable in the flood damage function, while Chang *et al*. [3] suggested that the flood depth alone is sufficient for flood damage estimation without considering other factors. The use of flood depth – damage curve has been explored by many researchers all over the world [e.g. 3, 14, 19, 23, 25, 26, 27, 28, 30, 31, 55, 65, 66, 67, 68].

The flood depth–damage curve can be represented in the form of depth-damage or depth-percent damage curve [23]. In depth-damage approach, the depth-damage relationships are developed directly from historical data while depth-percent damage curve is determined as percentages of damage to the total value of damaged property according to the corresponding flood depth. To obtain the depth-damage relationship, the percentages of damage value obtained from the depth-percent damage curve is multiplied with a replacement property value. In this way, for a similar site, a depth-percent damage function can be applied to any flood condition and not restricted to any fixed time [19, 23, 73]. Compared to depth-percent damage approach, a depth-damage curve is costlier and time consuming to prepare especially in getting reliable data. Furthermore, the useful life of the relationship is short as the type of curve is normally developed separately for many types of structures [23].

Flood damage function curve can be developed either based on damage data of historical floods or from hypothetical analysis known as synthetic stage-damage function. The latter approach is based on land cover, land use patterns, type of assets, and information from questionnaire survey [26]. In developed countries, the development of flood damage function curve is normally based on historical data [e.g. 26, 27, 56, 67, 69]. Dutta *et al*. [29] developed a flood stage-damage curve for urban and rural categories using the averaged and normalized damaged data published by the Japanese Ministry of Construction. The stage-damage functions by Jonkman *et al*. [27] were established based on empirical flood damage data from the historical events such as the 1953 catastrophic flood in Netherlands, local flooding in the river Meuse in 1993, in addition to information from literature and expert judgment.

Meanwhile, in the countries with limited flood damage data, synthetic approach can be used. There are two types of synthetic flood damage curves, i.e. either based on the existing historical databases, or using data based on interview surveys [22], as illustrated in Figure 1. Vonazaki *et al*. [33] applied a weighted Monte Carlo simulation to construct synthetic flow velocity-flood depth-crop damage curves. The loss information was collected from questionnaire survey involving practising and research agronomists. Logistic regression analysis was used to develop synthetic flow velocity-flood depth-crop damage surface for the selected crops in the study.
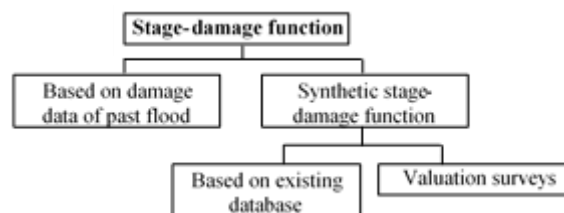

Figure 1 Flood damage function curve approach [73]

4.0 FUTURE DIRECTIONS FOR MALAYSIA

In producing a flood damage estimation model that is applicable to a developing country, the general methodologies from previous studies [e.g. 13, 19, 26, 31, 49] can be adopted. The estimation of flood damages may consider the elements of flood characteristics, characteristic of exposed element, value of exposed element and the relationship of flood damages with the respective flood parameters (flood damage function curve). Flood damage function curve is a combination of exposed property and the flood influencing factors, as predictors of event damages from which average annual damage can be calculated [25].

The available literatures on flood damage estimation in Malaysia (such as [35], [34], [36]) considered the four elements suggested i.e. flood characteristics, characteristic of exposed element, value of exposed element and flood damage function curve. However, the damage function used is adopted from other countries such as United State, Netherland and Australia. The study by Muhadi and Abdullah [34] for agricultural area does not apply flood damage curve. The flood damages were estimated from Fresh Fruit Bunch (FFB) price data from the Malaysian Palm Oil Board (MPOB) and vegetables and fruit price data from Department of Agricultural (DOA). For future flood damage

estimation works in Malaysia, it is suggested that a local flood damage function curve be developed to ensure the reliability of damage estimates and to reflect Malaysian own flood scenario.

The scarcity of flood damage data and information are major obstacles faced in conducting flood damages assessment studies [39], especially for developing countries. In Malaysia, the historical flood damage data is not well documented and not easily accessible. The damage data for certain flood event can be obtained from the respective District Office in the forms of replacement cost or compensation from the government. However, the available damage data are not suitable enough for flood damage assessment studies as they are too general and incomplete.

Hence for Malaysia case study, synthetic method is suggested due to scarce or incomplete data. Through synthetic approach, additional data can be generated from the primary data [25]. For this purpose, cross-sectional method can be used whereby the damage data is gathered by observing many subjects at the same point of time, without concerning the differences in time. Cross-sectional studies are done using questionnaires [70]. As suggested by McBean *et al*. [24] and Suriya *et al*. [39], interview survey questionnaire should be designed as a closed end type where the respondents can answer in a single word, in a short phrase or multiple choices. Merz *et al*. [12] recommended that in synthetic approach, the damage data may be collected via what-if-questions. What-if analysis measures the value of expected damage for a certain flood situation.

5.0 CONCLUSION

In summary, this paper has reviewed the various concepts used for the flood risk and damages assessment. The assessment of flood damages is based on two general approaches; 1) from existing data base, by carrying out interview survey or from secondary sources such as local authorities, newspaper and internet, 2) modeling approach that relates the damages with other related factors such as economic variables, and the nature of damage. In the modeling approach, the estimation of flood damages considered the elements of flood characteristics, characteristics of the exposed element, value of exposed element and the relationship between flood damages to the respective flood parameters (represented as flood damage function curve). Flood damage function curve is the key element in the assessment of flood damages. It can be constructed either based on historical damage data or by using synthetic method.

A development of a local flood damage function curve is suggested. For a developing country like Malaysia which has limited historical data, the synthetic and cross sectional data collection could provide a reliable option for the construction of flood stage-damage function curve.

Acknowledgement

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