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Research Article

Flood Vulnerability Assessment in Iskandar Malaysia Using Multi-criteria Evaluation and Fuzzy Logic

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Abstract: One of the most significant natural disasters in South-east Asia, is flooding. In Malaysia, for instance, Iskandar Malaysia region as a rapid urbanizing context located in southern peninsula has been affected by several flood events during last decade. Severe rainfall, natural situation, new unplanned developments and insufficient drainage systems mad the situation more considerable. This study seeks to address the crucial variables which contribute to the risk of flooding based on the characteristics of the region and develop a GIS-aided urban flood susceptibility map. The methodology emphasizes on uncertainty and multi-criteria which contribute to the risk of flood and increase the risk. As such, the Fuzzy logic, Multi-criteria ranking and Weighted Linear Combination (WLC) methods in Geographic Information System (GIS) are used to achieve the objectives. Distances from main stream, river and discharge channels, as well as other variables such as elevation, slope and land use are recognized as effective variables within the region. Final susceptibility map indicates that around 658 km^2 out of 1,614 km^2 within the region is under the high level of flooding risk. Different districts within the region include Pulai, Senai-Kulai, Tebrau and Johor Bahru can be considered as areas with a high risk of flooding. Natural and man-made situation influence the level of risk in each area. Generally the southern part of the region has a high level of risk as the consequence of conjunction between location of stream, lowland and land use type. Finally the situation in 2025 is investigated based on the proposed plan for 2025.

Keywords: Flood susceptibility, fuzzy logic, GIS, Iskandar Malaysia region, multi-criteria evaluation

INTRODUCTION

During last decade flood phenomenon has been recognized as the most frequent and devastating disaster in human settlement and causes nearly half of all victims of natural hazards. In the ten years prior to 2011, flood's economic loss was estimated around US $185 billion. Basically around 31% of economic losses that caused by natural hazards account for flood phenomenon (Ologunorisa and Abawua, 2005; Lawal *et al*., 2011; Alderman *et al*., 2012). Flood takes place when in a temporary time, normally dry land which is not planned for such an inundation, cover by water in a short time (Lamond *et al*., 2012; Sulaiman *et al*., 2012). Around 20% of world's population dwells in coastal ecosystems which have highest population density and face to the high risk of flooding (Levy and Hall, 2005). Developing countries, especially those located in sphere of monsoon, frequently expose to river flooding (Lawal *et al*., 2011). Climate change, antecedent soil moisture, deforestation, urbanization and river channel and floodplain modifications are identified as reasons that make the flooding more intensive and frequent (Chang and Franczyk, 2008). Environmental, social and economic aspects of society are affected in direct and indirect ways by flooding (Levy and Hall, 2005). In addition, more people will be put in jeopardy of flooding due to increasing levels of urbanization (Alderman *et al*., 2012).

Due to the more frequent flooding, destructive flood's impact and increasing the level of urbanization, the improvement in identifying and mapping the flood hazard seems to be crucial (Tingsanchali, 2012; Stefanidis and Stathis, 2013). Urban flood susceptibility maps can be used as appropriate tools for urban and regional planning and growth management (Fernández and Lutz, 2010). The purpose of this study is to present a regional flood susceptibility model and evaluate the model by means of uncertainty theory and multi-criteria evaluation. The study is carried out in the rapid urbanizing context of Iskandar Malaysia Region, located in southern parts of Malaysia to indicate the combination of natural and man-made factors in increasing the risk of flood. As such, in this study the fuzzy logic, multi-criteria ranking and Weighted Linear Combination (WLC) methods in Geographic

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Information Systems (GIS) are used to produce flood susceptibility model (Malczewski, 1999; Ologunorisa and Abawua, 2005; Kainz, 2006; Al-Hanbali *et al*., 2011).

FLOOD DEFINITION AND ASSOCIATED VARIABLES

Flood is identified as one of the most perilous, devastating and frequent phenomenon in human settlement. This hazard causes water overflow in the areas which are not planned for such inundations and water level arises more than normal situation in short time (Mackenzie and David, 1998; Lamond *et al*., 2012; Sulaiman *et al*., 2012).

Flood has tremendous short term and long term impacts on human life, sanitation and jeopardizing environmental, social and economic aspects within the society. Normally, infrastructure and property loss, damage to building and agriculture can be considered as flood's direct impact, while health problems, chemical pollution, water-borne infection are recognized as indirect flood's effects (Lawal *et al*., 2011; Lamond *et al*., 2012). Urbanization trend and human activities such as rapid and unplanned settlement, land use change, uncontrolled building construction, deforestation and removing soil and vegetation affect the hazard's pattern and frequency (Konrad, 2003; Pradhan, 2009; Fernández and Lutz, 2010; Montz and Tobin, 2011). Consequently, the amount of runoff within the urbanized area enhances. Also, flood velocity increases due to increasing the volume and peak discharge of runoff (Konrad, 2003).

VARIABLES AND FACTORS OF FLOOD IMPACT

This research conducted an intensive literature review and has gone through relevant studies to identify the most appropriate variables to generate flood susceptibility maps. The followings are the variables which are selected based on the area characteristic and available data:

Distance from main stream and river: Areas which are located near the stream and river have high risk of flooding. Water overflow during the flood incident makes the adjacent area much more vulnerable and influence the water velocity as well (Paquette and Lowry, 2012).

Elevation: Topography and physical characteristic of the built environment must be considered due to the risk exposure and hazard vulnerability. Topography affects the flood severity, flow size and direction (Kia *et al*., 2012; Saini and Kaushik, 2012). Normally, areas which have lower elevation, affect by flood more than higher land. In addition, water remains in the lower area for a longer time (Fernández and Lutz, 2010; Kia *et al*., 2012; Saini and Kaushik, 2012; Jianfen *et al*., 2013). Low-laying area is recognized as the most vulnerable area within the flooding due to the quick inundation. Moreover, because of the gravity, water pulls toward low-laying area that makes the impact significant (Paquette and Lowry, 2012).

Slope: The topographic slope is defined by the angle between surface and a horizontal datum (Kia *et al*., 2012). Slope has impact on the amount and velocity of runoff and improper use of slope increases the flood hazard risk. Large amount of runoff water retain in a flat area for longer time and increase the damages. Sharper slopes cause more rapid flow (Smyth and Royle, 2000; Fernández and Lutz, 2010; Kia *et al*., 2012; Saini and Kaushik, 2012).

Land use and land cover: Flood incidents are also influenced by the types of land use and land cover. Infiltration capacity is different for each land use category. Water body has the highest capacity to absorb the water. In contrast, impervious surfaces including which cover most part of the urban area have the lowest infiltration capacity. Flood occurrence conversely relates to the vegetation density. Vegetation and green space act as protective land cover and control the runoff and water overflow (Kia *et al*., 2012; Saini and Kaushik, 2012; Jianfen *et al*., 2013; Stefanidis and Stathis, 2013). Therefore, it can be concluded that due to the more impervious surface, change in natural hydrologic situation and lack of vegetation within the urbanized area, lag time decreases, amount of runoff, peak discharge and total discharge increase and the risk of flooding will be influenced (Konrad, 2003; Fernández and Lutz, 2010; Paquette and Lowry, 2012).

Population density: Population density provides information to recognize the area with higher concentration of the population. In an area with higher population density more people and infrastructure are likely to be affected by the flood (Chang and Franczyk, 2008; Paquette and Lowry, 2012; Saini and Kaushik, 2012).

Distance from discharge channel: Some areas which are remarkably affected by flood, situated near to the channel and affected by channel overflow during the flood. Distance interval must be defined based on the class of discharge channel. Based on Fernández and Lutz (2010) appropriate distances form discharge channel interval are <100 m, between 100 and 500 m, between 500 and 1000 m and >1000 m while based on Paquette and Lowry (2012) distance intervals which are used to assess the risk are considered as <100 m, between 100 and 200 m, between 200 and 1000 m and >1000 m. Accumulation of huge amount of water in area with high density drainage network increases the risk of flooding (Kia *et al*., 2012).

DEVELOPING A FLOOD SUSCEPTIBILITY MODEL

Flood's genesis indicators identification is recognized as the most important steps of flood risk assessment to ensure that the entire problem is encompassed (Stefanidis and Stathis, 2013).

Different methodologies have been used to conduct the flood risk assessment and evaluate the situation. Flood is recognized as complex phenomenon; therefore, methodologies that emphasize on uncertainty theory and multi-criteria evaluation are suitable to be utilized in flood hazards studies. Based on the flood characteristic, mathematical and statistical analysis (Pandey and Nguyen, 1999), quantitative methods, Multi Criteria Decision Analysis (Kubal *et al*., 2009; Levy *et al*., 2007; Musungu *et al*., 2012), system dynamic method (Kia *et al*., 2012) and uncertainty methods (Hundecha *et al*., 2001; Levy and Hall, 2005; He *et al*., 2011; Li, 2013) are identified as most frequent methodologies to assess the flood risk (Jian *et al*., 2009). Flood risk includes statistical probability of occurrence and degree of potential consequences. Various variables and indicators associate with the risk of flooding and affect the risk (Ologunorisa and Abawua, 2005; Shimokawa and Takeuchi, 2006). Some occurrences indicate a level of vagueness which cannot be demonstrated appropriately with firm sets of class boundaries. Also clear boundaries for some spatial features may be difficult to be assigned strongly.

Basically, four primary approaches are considered to categorize uncertainty:

- Stochastic programming approach
- Fuzzy programming approach
- Stochastic dynamic programming
- Robust optimization

In stochastic approach, some variables are considered as random variable with known probability distribution. Fuzzy programming as the second approach tries to find solution regarding some variable as fuzzy numbers. Stochastic dynamic involves applications of random variables that can be perceived in all area of multi-stage decision making. In compare with other approaches, the last approach stands for uncertainty setting up various scenarios which indicate realization of uncertain parameters to find out a robust solution to prove that all specific scenarios are "close" to the optimum in response to change the input data (Mirzapour Al-E-Hashem *et al*., 2011).

Fuzzy method is recognized as uncertainty method that is applicable for vague phenomena. In addition fuzzy logic provides rational basis for solving the problem in incomplete, inexact or not completely reliable environment. Probabilistic logic and probability theory involve in this method as well (Zadeh, 1988; Kainz, 2006). This method deals with uncertainty and approximation rather than exact modes of reasons, everything involves truth, can be a member of the set and recognized as a matter of degree (Zadeh, 1988). A fuzzy set is considered as a class of objectives with continues grades of membership. Fuzzy set is defined by a membership or characteristic function in which each objective is apportioned a grade of membership in a range of zero and one (Zadeh, 1965). Fuzzy logic includes spatial cases not only classical two or multi valued logic. Therefore, degree of membership to a set of fuzzy can be considered as an appropriate method in this research.

Flood factors are standardized to a continuous scale in a GIS environment by fuzzy membership functions (Aydi *et al*., 2012). Then weight is assigned to the defined variables by using the rating method and variables are combined to achieve the expected output.

Multi Criteria Decision Making normally involves in evaluating the criteria with different degree of importance. Weight can be realized as value that is assigned to criterion for evaluating its importance. Normally larger weight expresses the more importance the criterion is. Four main types of techniques namely, ranking methods, rating methods, pairwise comparison methods, trade-off analysis methods and comparing methods are available for developing the weight (Malczewski, 1999). In this research ranking method is used to reclassify the indicators, then fuzzy membership types are set based on expert opinion to each variable and rating method is used to assign the weight to variables.

Weighted Linear Combination (WLC) technique is considered as rule for decision making in complex maps in the GIS environment (Al-Hanbali *et al*., 2011). Weighted linear combination, or simple additive weighting formed based on the idea of weighted average. In respect to this idea, continuous criteria must be standardized based on numeric range. The weight of each criterion is directly allocated based on the level of importance. Eq. (1) elaborates the function:

$$S = \sum W_i X_i \qquad (1)$$

where, S indicates the flood susceptibility index, Wi indicates the weight of criterion constrained to sum to 1, Xi shows value of each factor that is the standardized score of the criterion and i indicates the number of criteria (Drobne and Lisec, 2009; Aydi *et al*., 2012). Each input is used in raster format with a cell size of fifty meters (50×50). In this study flood's indicators are combined to create the flood susceptibility map for the region.

Multi-criteria analysis evaluation includes a broad range of activities that are outlined in this section to indicate the overall reliability of developed model. This

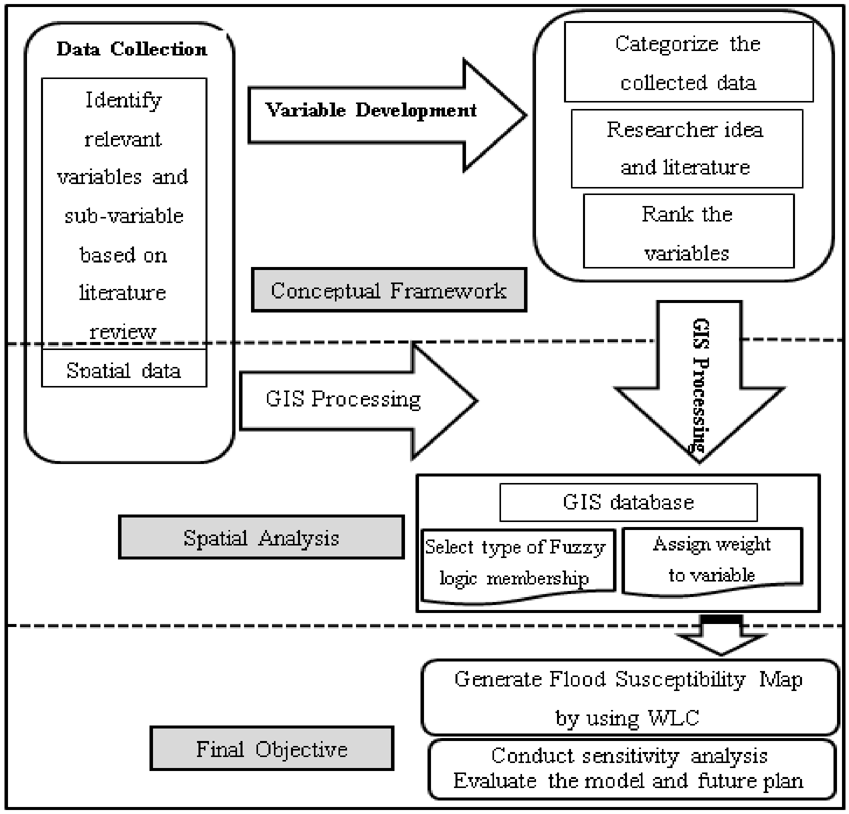

Fig. 1: Methodology framework

technique provides basis to verify the result of the decision to clarify how changes in judgment or degree of importance for each variable affect the output and how much each individual variable as individual source of uncertainty contribute to the final result. Therefore, uncertainty that is associated with output of GIS-based modeling and degree of complexity can be assessed. When the weights of variables are varied over a range of interest, sensitivity analysis is considered as a method to evaluate the model (Drobne and Lisec, 2009). Variable weights and variable values are recognized as the two most significant factors in sensitivity analysis. Variable weights are more important in sensitivity analysis due to the subjective amounts which are calculated based on expert's opinion and incorporate a high probability for errors. In practice, sensitivity analysis is conducted by applying different weighting values for the main decision variables. The total weight that assigned to all variables should always be equal to 1 or 100%. Therefore, sensitivity analysis must be considered as simultaneous variations in the weights of more than one variable. Hence, there are various possibility for variable weight deviations by using different weight for more than one variable in a consistent rang (Crosetto and Tarantola, 2001; Sadeghi-Niaraki *et al*., 2011). Figure 1 indicates the methodological framework of this study:

STUDY AREA

Asia and pacific confront with variety of natural disasters (Shaluf and Ahmadun, 2006). In Malaysia, which is located near equator line in South-East of Asia, flood is recognized as the most frequent phenomenon in terms of affected people, expansion, frequency environmental, social and economic damages. 9% of total land that is equal to 29,800 km^2 is recognized as flood prone area (Mohd *et al*., 2006; Kia *et al*., 2012). Flood effects in Malaysia are considered as combination of natural and man-made factors. Natural factors such as extreme monsoon rainfall, climate change, rain storm and shallow river coupled with man-made factors including unorganized development, emerging squatter settlements, poor drainage, deforestation and land use change (Pradhan, 2009; Sulaiman *et al*., 2012). The reasons of flood event are recognized as rapid urbanization trend, enormous development and heavy rainfall in short time period. In 2006 and 2007 due to the massive monsoons rainfall, eastern and southern part of peninsular Malaysia experienced destructive floods. In southern part, the state of Johor and especially the city of Johor Bahru faced severe flood which is a hard hit by the flood effect (Pradhan, 2009).

This study is carried out in Iskandar Malaysia (IM) region, which is recognized as a corridor for economic

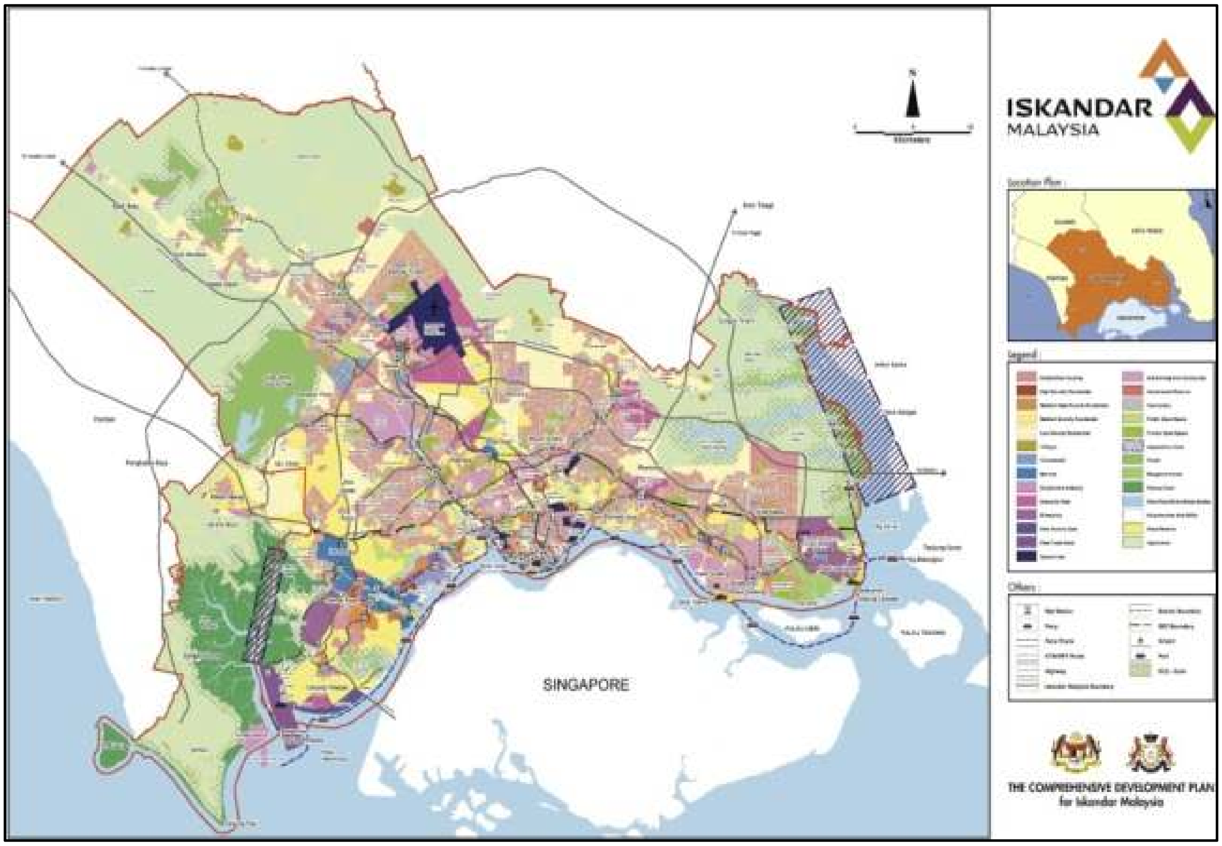

Fig. 2: Location and major land uses of Iskandar Malaysia region in southern Malaysia (Rizzo and Glasson, 2012)

development since 2006. IM is one of the regions in the country that the flood hazard has been envisaged in it more frequent in recent years due to the high and rapid urbanization trend.IM has been promoted based on Comprehensive Development Plan to improve physical and economic situation of Johor Bahru metropolitan area. IM region covers around 220,000 ha. In terms of weather, the study area is located in a tropical climate with the diverse daily temperature from 24°C until 32°C. Overall, the topographic condition is up to 640 m and the lowest is about 2 m from the sea level. Flood influenced some locations within the region during 2006 and 2007 that is recognized as the worst disaster in 100 years (Hisham *et al*., 2009; Rizzo and Glasson, 2012). Figure 2 shows the location of the study area.

FACTOR CLASSIFICATION, STANDARDIZATION AND WEIGHTING

In order to generate flood susceptibility map, natural and man-made variables are selected based on area characteristic (Ologunorisa and Abawua, 2005; Popovska and Ivanoski, 2009; Fernández and Lutz, 2010; Sulaiman *et al*., 2012; Stefanidis and Stathis, 2013). Distances from main stream and river, elevation, slope, population density as well as man-made variables such as land use and distances from discharge channels are recognized as effective variables within the region. Population density and infrastructure layers are used to assess the flood vulnerability after developing and evaluating the model. The relevance of the variables and their classification are described below:

Distance from main stream and river: In the case of IM region distance from main stream and river have great impact in flooding. According to the records, the most affected areas during flood events are located near these natural features as a consequence of water overflow. Therefore, distance from main stream is identified as the most important input for the model. Distance from main stream interval that is used in this study identified as: a) <1000 m, b) between 1000 and 2000 m, c) between 2000 and 5000 m and d) >5000 m. Distance intervals from river are identified as: a) <100 m, b) between 100 and 500 m, c) between 500 and 1500 m and d) >1500 m.

Elevation: Study area is located in southern part of peninsula Malaysia where elevation rate is between 2 to 640 m above the sea level. Highest point is located in Senai-Kulai district in the center of region, while the lowest part is located in Jeram-Batu in the southern part. In addition, level of the water during the floods on 2006 and 2007 is recorded around 5 m which means that the areas with elevation below 5 m have high risk of flooding. Therefore, according to the records and flood susceptibility point of view three classes are created form Digital Elevation Model (DEM) by using a digital contour map: a) 1 to 5 m, b) 5 to 10 m and c) > 10 m.

Slope: Slopes within the region vary from more than 50% in Senai-Kulai district to the less than 1% in southern districts. The slope map is generated by using the DEM and it is divided into eight classes of degree, according to steeper slope which causes more hazardous and quick flow (Fernández and Lutz, 2010; Kia *et al*., 2012): 0-3, 3-5, 5-10, 10-15, 15-20, 20-30, 30-40, 40-50 and >50.

Land use and cover type: Based on the current land uses within the region which influences the risk of flooding in different ways, eleven categories namely road and transportation, residential area, industry, institution and community facility, utility and infrastructure, commercial, vacant land, open space and recreation, agriculture, forest and water bodyare identified to create this layer.

Population density: Population density for each district is calculated to indicate the situation in each area.

Distance to the discharge channels: The values that are adjusted to distance from discharge channel for this study are <100 m, between 100 m and 500 m, between 500 m and 1000 m and >1000 m Generally, the weight that is assigned to each variable depends on the area (Fernández and Lutz, 2010; Jianfen *et al*., 2013).

The fuzzy membership type: Basically, eight variables are recognized as significant factors which contribute to the risk of flooding within the region. Based on each variable's contribution to the risk, each variable is divided into sub-variable. To reclassify the variable, rank must be assigned to each sub-variable based on literature review and expert's opinion to specify the level of importance.

Table 1: Information which is used to create flood susceptibility map in Iskandar Malaysia

Variable	Sub-variable	Rank	Fuzzy function	Weightage
Distance from main stream	1000 m	1	Small	21
	2000 m	2		
	5000 m	3		
Elevation	<5 m	1	MS Small	18
	5-10	2		
	>10	3		
Slope (in terms of water velocity)	0-3	8	Small	16
	3-5	7		
	5-10	6		
	15-20	5		
	20-30	4		
	30-40	3		
	40-50	2		
	50<	1		
Land use	Road, transportation	11	Small	13
	Residential area	10		
	Industry	9		
	Institution, community facility	8		
	Utility, infrastructure	7		
	Commercial	6		
	Vacant land	5		
	Open space, recreation	4		
	Agriculture	3		
	Forest	2		
	Water body	1		
Population density	1000-9991	0-255	Large	11
Distance from river	100	1	Small	9
	500	2		
	1500	3		
Slope (in terms of lag time)	0-3	8	Large	7
	3-5	7		
	5-10	6		
	15-20	5		
	20-30	4		
	30-40	3		
	40-50	2		
	50<	1		
Distance from discharge channel	100	1	Small	5
	100-500	2		
	500-1000	3		
Total				100

Fuzzy membership type must be set for each criterion to assign the level of risk and standardize the layer. Fuzzy membership must be selected based on the data characteristic and the way that data contribute to the risk of flood. Three types of fuzzy membership including Fuzzy MS small, Fuzzy Small and Fuzzy Large are used to prepare the data layer. Fuzzy MS small is used when very small value have higher possibility to be a member of data set. For instance, the elevation layer dataset is defined between 0 to 640 m; with the area of elevation below 5 m as the highest possibility in terms of flood occurrence. Therefore, elevation layer is arranged and become standard by using Fuzzy MS small function. Fuzzy Large is used when larger value have more possibility to be a member of data set while Fuzzy Small is used when the value with smaller amount have more occurrence possibility.
Fuzzy Large is used to set the slope (in terms of lag time) and population density layers. Other layers including distance from main stream, river and discharge channel, land use type and slope (in terms of water velocity) are arranged by using the Fuzzy Small function. Application of fuzzy membership method provides a basis to classify the data in a range between 0 and 1. The values which are assigned as 0 do not have possibility for flood occurrence, while the value of 1 defines the locations with highest possibility of flood occurrence. In addition, weight is assigned to each variable based on rating methods. Table 1 indicates variable, sub-variable, assigned rank for reclassification, fuzzy membership type and the associated weight which is used to create flood susceptibility map in an Arc GIS 10.0 environment.

The total weightage which is assigned to variables is equal to 100. Therefore, after multiplying the weight and value of each layer and calculate the final result by using Weighted Linear Combination (WLC), an accurate comparison between different locations based on the value of raster cells is possible. According to the weight, distance from main stream is identified as the most important variable; because historical records indicate that the areas which are located close to the main stream are highly affected by previous flood. Elevation is defined as the next significant factor because low-laying areas are inundated by water over flow quickly. In addition, water pulls into the low-laying area due to the gravity. Slope (in terms of water velocity) is identified as the next important item due to the damages which are caused by the water speed during the flooding. Land use type is set as the fourth significant factors due to the transforming from natural situation to impervious surface. During the flooding event more people and properties are affected by flooding in areas with higher population density, therefore, population density is recognized as the next important factor. Distance from river, slope (in terms of lag time) and distance from discharge channel are the other influential factors.

RESULTS AND DISCUSSION

Model validation: In order to validate the generated flood susceptibility map, historical records related to the previous floods are considered to be compared with the developed maps. Based on the information until 2011, approximately 45, 524 km^2 of total lands are affected by flood.

According to location of flooded area and generate model, the model covers all the area which faced the flood; level of risk in these areas indicates a high level with considerable intensity. Figure 3 indicates the general flood susceptibility map and real flooded area.

General finding: Based on the Iskandar Malaysia flood susceptibility map, approximately, 20% of total land is faced to the high level of risk. Highest level of risk is identified as 88.57%. Pulai, Tebrau, Senai-Kulai and Johor Bahru districts can be considered as more urbanized areas which previously have experienced flood hazard. By investigating the flood's behavior in each district significant variables which affect the risk of flooding can be considered:

In Tebrau, western part of the district indicates as an area with high level of risk. Stream location and land use types are considered as significant variable which influence the risk in this part.

Within Pulai district, variables such as slope, elevation and location of stream are more associated with the risk of flood.

In Senai-kulai, central part indicates a high level of flood risk due to the conjunction of stream location and land use type. However despite the existence of rivers in western part of Senai-Kulai district the level of risk is low due to the high elevation. Therefore, streams location, elevation and land use type are the influential variables.

In Johor Bahru district, location of stream, low-land and land use type can be mentioned as variables which contribute to the risk of flood.

In Sungai Karang, TanjongKupang, Jelutong and JeramBatu district, despite of dominant land use which is forest and agriculture land, stream location and low elevation enhance the risk of flood.

Stream and river are the existing natural features in every district which affect the flood and increase the risk. Basically, districts that are located near to the stream and river experience high risk of flood due to the water velocity and overflow. Elevation as another significant natural feature influences the flood event. The lowest elevation in study area, with 2 m from the sea level, is located in JeramBatu, while Senai-Kulai has the highest elevation up to 640 m. Area with high slope degree is located in Senai-Kulai, around area with high elevation. Other part mostly have slope between 0 and 5°.

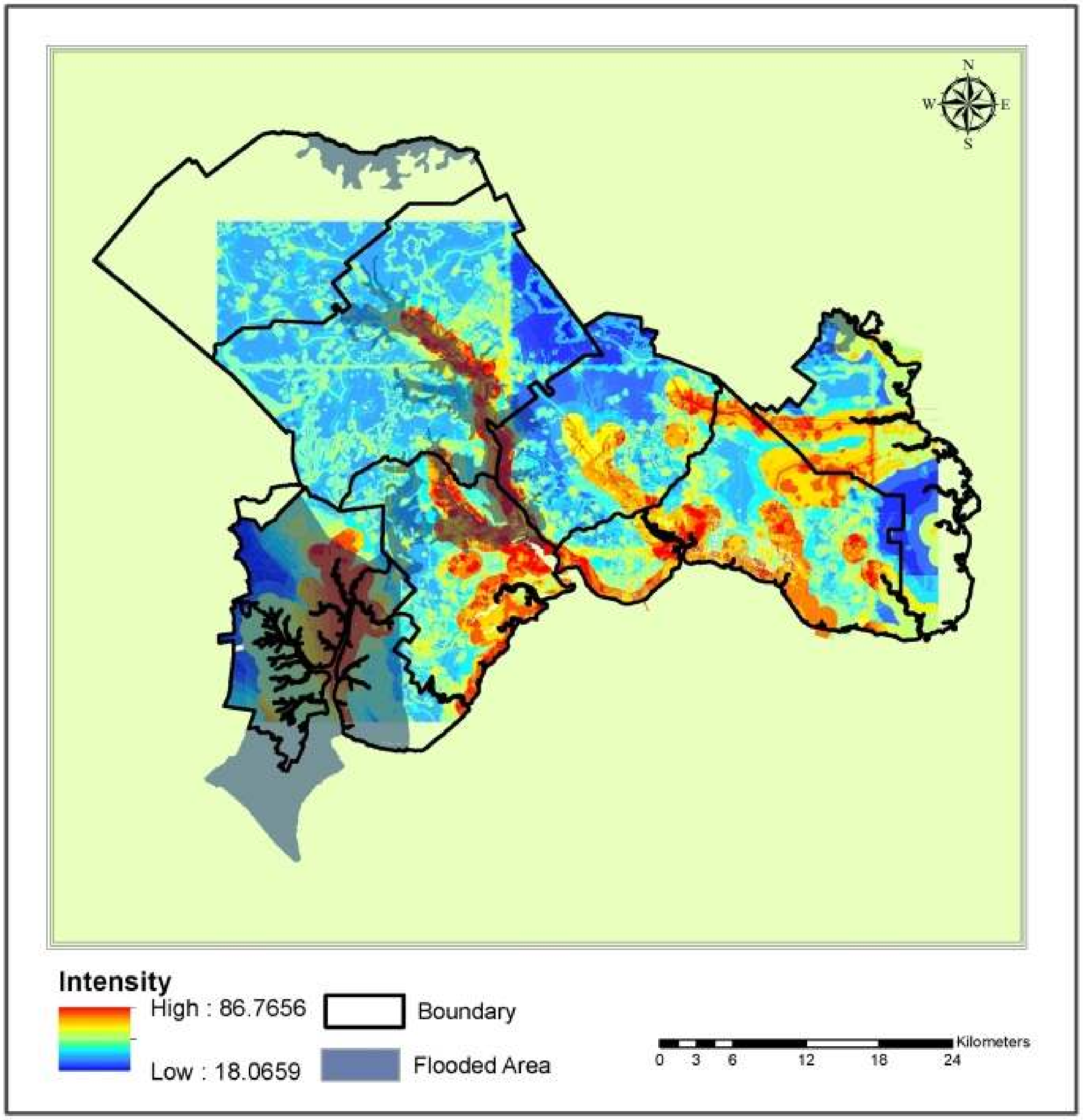

Fig. 3: Comparison of real flooded area and generated flood susceptibility map

Land use type is considered as another significant factor which affects the risk of flooding due to the impervious surface. In Johor Bahru most of the land is occupied by built up area, road and transportation, residential area, institution and community facility are the dominant land use and cover around 48%, while forest occupies only 1.77% of total land. In Pulai and Tebrau, road and transportation and residential area cover around 34 and 30% of total land respectively. In Sungai Karang, TanjongKupang, Jelutong and JeramBatu lands are mostly covered by forest and agricultural land. Road, transportation and residential area just occupy around 7% of total land in this district which is the lowest compare to other districts. In Senai-Kulai 64% of land is occupied by agriculture. In Kulai, around 12% of land is covered by forest which is the highest percentage compared to Johor Bahru, Pulai and Tebrau. Percentage of built up area in Johor Bahru is highest, while in other districts the percentage of non-built up area is dominant.

Real flood situation indicate that under the same natural situation including location of the stream, elevation and slope in northern part of Senai-Kulai area with more impervious surface are affected by flood more than the area with forest, agriculture and open space (Fig. 4). In addition, transformation of the natural situation causes conversion to more impervious surface and hydrological changes. Hence, risk of flooding affect by land use type due to the more pick discharge and water runoff. In urbanized area more people and properties expose to the flood and based on the risk definition the risk of flooding increase in this area as well. Despite of appropriate land cover and less impervious surface due to less built up area, in Sungai

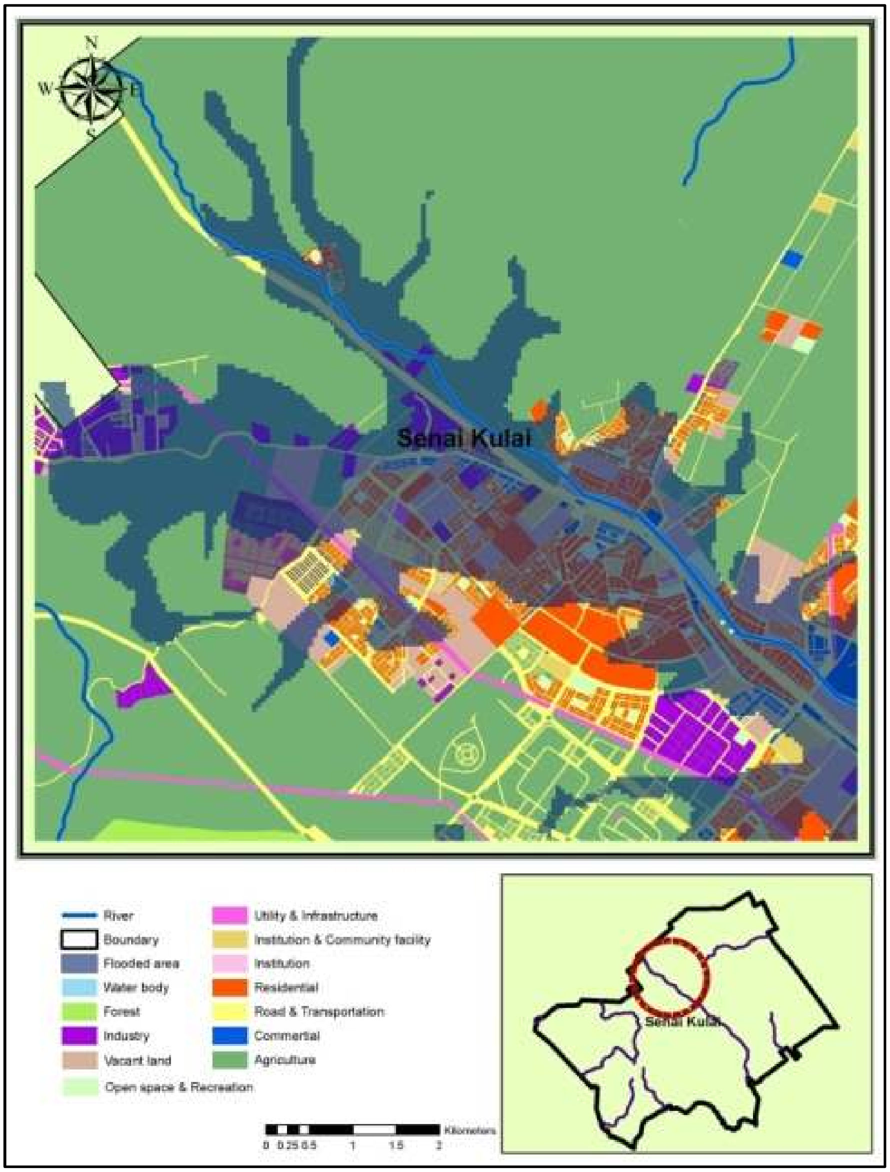

Fig. 4: Flooded area in Northern part of SenaiKulai

Karang, TanjongKupang, Jelutong and JeramBatu, these districts experienced flood previously and most of the lands in these districts are covered by flood compared to other districts. In Johor Bahru, location of stream and low elevation associated with more impervious surface and make the situation more hazardous. In addition, due to the high population density, more infrastructure is developed and consequently the risk of flooding increases.

Uncertainty and model sensitivity analysis: In this study distance from main stream as significant natural factor and land use type as important man-made variables are selected to evaluate the model using different range of value. Other variables remain consistent during this analysis. Due to the different weights which are assigned to the variable, the level of risk of flood and area under high risk are changed. The effect of changing of the weight must be compared with real flood evidence to find out how the situation changes in terms of level of risk and area under the risk of flooding and which range of value lead to an accurate model. In the basic model land use weight is assigned as 13; in the four attempts the weight decreased to 11, 9, 6 and 4, respectively. On the other hand, the weight of distance from main stream which is assigned as 21 in the basic model increased to 23, 25, 28 and 30, respectively. In four other attempts the weight of land use increased to 16, 18, 23 and 28 while the weight of distance from main stream decreased to 18, 16, 11 and 6, respectively.

Table 2: Sensitivity analyses results

"Land use" Rate	"Distance from main stream" Rate	Risk intensity Highest	lowest	Note
28	6	89.31	18.95	Increase the level of risk in the area in which "land use" is considered as dominant variable
23	11	88.73	18.79	
18	16	88.15	18.58	
16	18	87.92	18.49	
11	23	87.81	18.45	Increase the level of risk in the area in which "Distance from main stream" is considered as dominant variable
9	25	87.11	18.19	
6	28	86.76	18.06	
4	30	86.53	17.98	

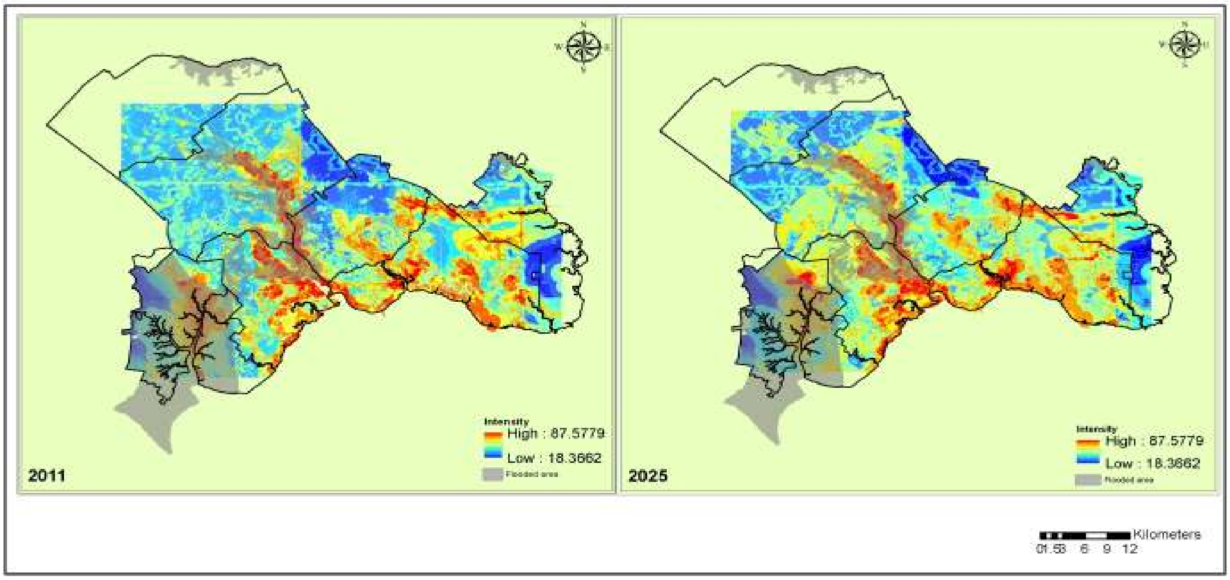

Fig. 5: Flood susceptibility map for 2011 and 2025

Basically, risk intensity is increased as a result of increasing the rate of land use. According to sensitivity analysis it can be inferred that by changing the rate of specific criterion, risk intensity and the area under the high level of risk changes as well. Based on the basic model and achieved risk intensity which is indicated 87.57 and 18.36 percent as the highest and lowest risk intensity within the region, the value between 16 and 11 for land use and range between 18 and 23 for distance from main stream can be considered as appropriate range for the model. Table 2 shows the results of sensitivity analyses under different condition:

Generated model based on proposed plan for 2025: The model of flood in IM Region for 2025 is generated based on proposed Iskandar Malaysia Comprehensive Development Plan (CDP, 2006) and calibrated using the values achieved in the previous stage. In the model the natural features are assumed to remain constant. Also, population density is estimated for target year based on the calculation of normal population growth rate. Based on the CDP for 2025, built up areas will increase in the region, replacing the vacant land and agricultural land. Therefore, more areas are considered as high level of risk in terms of impervious surface.

This situation is remarkable in Tebrau, Senai-Kulai and Pulai. Generally, between 2011 and 2025, percentage of built up area is increased from 45 to 78%, while percentage of non-built up area decreased from 55 to 23%. Figure 5 indicates that how the risk of flooding within the region is increased from 2011 to 2025. As a conclusion, in the districts which are supposed to have more built up area, the risk of flooding increases due to the change in land use type and intensive constructions.

Vulnerability assessment: Risk is defined as combination of hazard, people and property exposure to hazard and vulnerability of human and property which are exposed to the event (Camarasa Belmonte *et al*., 2011). Therefore, to assess the vulnerability within the region, combination of building and infrastructure locations and population based on census data for 2013 is carried out through GIS overlay method to indicate areas with high vulnerability. According to the output and comparison between the generated flood susceptibility maps, Johor Bahru, Pulai, Tebrau, Plentong and Senai-Kulai districts are more likely to be highly vulnerable to the flooding. In general, based on the vulnerability assessment Johor Bahru, Pulai, Tebrau, Plentong and Senai-Kulai are considered as the vulnerable districts in terms of risk of flooding due to the conjunction of natural situation and high population and property density.

CONCLUSION

Flood is recognized as the most common natural hazard and a complicated phenomenon. Basically, natural hazards such as flood are inevitable phenomenon but by controlling the natural and man-made factors adopting appropriate tools the environmental damaging effects can be mitigated. Flood risk assessment is a complex and uncertain process. This study carried out an evaluation of various indicators which are associated with risk of flood in Iskandar Malaysia as a rapid urbanizing context. Natural and man-made variables contribute to the risk of flood in the study area. The study indicated that an inappropriate use of natural environment can lead to unsustainable plan and influence the development from environmental, social and economic aspects. Stream location and elevation are recognized as effective natural factors within the study area. On the other hand, man-made variables increased the risk of flood due to the change in natural condition and also their own damaging impacts. The study identified the development of impervious surface by associated land use types as the most effective man-made impact on flood risk. This study indicated that flood susceptibility map can be considered as a powerful tool for planners and decision makers to assess the level of risk and evaluate the current and future situation to mitigate the risk and vulnerability. In addition, this tool can be used to organize and implement proper projects for flood protection and flood mitigation. Noteworthy, in coastal area and areas which face to the risk of flooding due to the natural situation the flood susceptibility maps are helpful. In addition, flood susceptibility map can be utilized to indicate areas under different level of risk and find out effective variables for sustainable development.

This study can be improved by applying more advanced optimization methods such as artificial neural network, or colonial algorithm in classification of variables as well as incorporating more accurate data. Besides, the study can be improved if the interdependencies of flood generation variables are examined. So, the researchers serve these improvements as future development in study on flood in highly urbanized regions.

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