

Spatial and Temporal Flood Risk Assessment for Decision Making Approach

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Abstract. Heavy rainfall, adversely impacting inundation areas, depends on the magnitude of the flood. Significantly, location of settlements, infrastructure and facilities in floodplains result in many regions facing flooding risks. A problem faced by the decision maker in an assessment of flood vulnerability and evaluation of adaptation measures is recurrent flooding in the same areas. Identification of recurrent flooding areas and frequency of floods should be priorities for flood risk management. However, spatial and temporal variability become major factors of uncertainty in flood risk management. Therefore, dynamic and spatial characteristics of these changes in flood impact assessment are important in making decisions about the future of infrastructure development and community life. System dynamics (SD) simulation and hydrodynamic modelling are presented as tools for modelling the dynamic characteristics of flood risk and spatial variability. This paper discusses the integration between spatial and temporal information that is required by the decision maker for the identification of multi-criteria decision problems involving multiple stakeholders.

1. Introduction

Flooding is widely natural hazard that noticeably affects social, economic and environmental issues. Flood risk management is of utmost importance to identify the design, planning and methods of flood protection to ensure the sustainability of community development. However, the traditional flood protection method only focuses on structural flood mitigation, rather than non-structural measures. In the perspective of flood risk management, a flood protection method should incorporate stakeholders to develop and implement the adaptation alternative to minimize the effects of flood impacts, mainly in floodplain areas.

However, due to the uncertainty of flood prediction, many vulnerability and adaptation assessments should be considered in the research of floods. There are many types of uncertainty in flood management, from hydrologic, hydraulic, geotechnical, and structural uncertainties, to economic, environmental, ecological, social and political uncertainties[1]. According to Baecher (2009), flood risk management related to disasters involves hazard, vulnerability and consequence assessments [2]. However, vulnerability and adaptation assessments cause difficulty in making decisions, due to the uncertainty of flood predictions. Dynamic and spatial characteristics of flood should be considered in decision making. Spatial and temporal dynamics of parameters related to floods were analyzed in prediction of where and when a flood might occur [3].



For this reason, a continual process in the vulnerability of flood risk management is significant to identify the weaknesses of the current situation, and suitable methods for the selection, exploration and monitoring of the best adaptation strategies and measures that can be applied in the decision-making process. Nevertheless, time is not taken into account in the vulnerability assessment for flood prediction. Thus, temporal dimension should be considered in vulnerability assessment studies, in order to capture changes dynamically. In this research, value of critical rainfall is used for the temporal prediction of a flood.

The framework was prepared for the comprehension of the flood-related decision-making process. The aim of the study is to predict flood vulnerability in terms of spatial and temporal, as well as to provide information and guidance to the decision maker to take the right action towards adaptation to flood problems. Thus, integration between flood vulnerability assessment and decision making is needed to develop adaptation strategies in decreasing the adverse effects of flooding.

2. Flood Mitigation

Due to the recurrent nature and adverse impacts of flooding, flood mitigation is necessary to be carried out, involving the management and control of floodways. The management of a flood disaster is a multidiscipline approach, involving hydrology, management of water resources, economics, statistics, population, public policy and planning [4]. The regulation and flood controlling works should be implemented in a floodplain area by improving flow of floodways, and constructing a continuous system of dykes, in order to minimize loss of properties, damage, and human lives.

The efficiency of a flood hazard assessment in producing flood mitigation requires flood conditions such as historical data, depth of inundation, flow velocities, and extension area where effected by the flood. Some of the flood characteristics can be obtained from a flood model. Hydrodynamic modelling is a practical method in flood assessment resulting from a flood prediction event, that can be developed using historical events, condition of previous events, and modification conditions for future events. Hydrodynamic models are used to estimate design floods in a study area, and generate a flood inundation model for an early warning system. This modelling assists the understanding of flood hazards, and effects of mitigation including structural (curative) and non-structural (preventive) measures to alleviate flood problems.

3. Modelling Approach

In Malaysia, research on flooding is mainly based on the development of hydraulic models, with an emphasis on a structural approach, using engineering measures including building of seawall, revetments levees, and river embankment. The combination of various flood frequencies and various mean annual floods by region have been used in developing a hydrological model to estimate a design flood for Peninsular Malaysia[5]. The prediction of flood frequency using the artificial neural network (ANN) and statistical theory is the frequent method to use instead of stochastic models [6]. However, this model can only be applied if the recurrence intervals of the highest discharge do not exceed the lengths of recorded highest discharges data without considering the maximum flood hydrograph.

Various hydrological models have been applied to flood design. Source code is one of the important criteria of flood design, which has the capability to support the full parameters and dimensional overland routing approach. Nowadays, these models are available in different types of dimensions, from 1D dimension models, to complex 3D models which take flow direction into inundation of flood.

However, the changes of the environmental process in four dimensions of time and space must be considered in the study. Therefore, a combination simulation model and GIS can be used as a plausible solution in providing the potential to analyze the environmental process in spatial and temporal aspects. In addition, environmental problems are different in all places. Hence, generic solutions developed by using the interaction of the dynamic spatial model can be applied to each society and location, which provides relevant information for the decision-making process. The interaction of

spatial, temporal and decision making should be measured and addressed in the process of environmental modelling.

4. Methodology

Figure 1 represents the input, research activity and expected output for each step of this research, which is a systematic assessment of flooding. The integration of approaches combines many disciplines which will be used to assess the vulnerability and adaptation to flood. The development of the hybrid spatio-temporal model using a combination of the Geographic Information System (GIS) and the System Dynamics (SD) modelling approaches, meanwhile a multi-criteria decision model will be used in assessing adaptation alternatives.

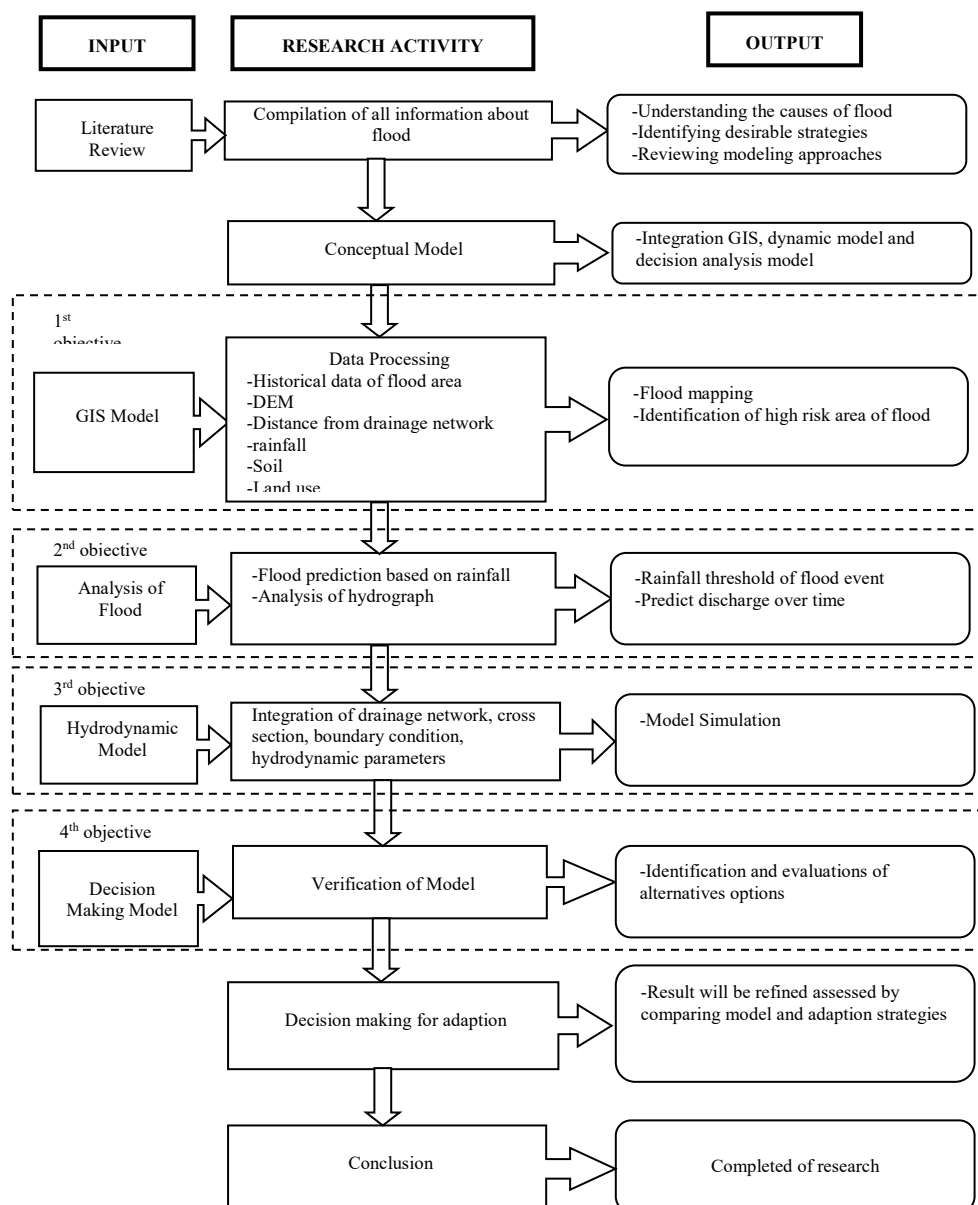


Figure 1. Flowchart of the research

4.1. GIS Model

Spatial analysis is an important component of the integration of the spatial and temporal model to organize all initial data required for the flood assessment process. Additionally, it was developed in support of data visualization and data conversion by the Geographic Information System (GIS).

Flood hazard mapping will be produced using a frequency ratio model to evaluate the influence of classes of each conditioning factor on flood occurrence. Frequency ratio models are used based on the assumption that the recurrent flood will occur under a similar condition as the previous flood, using relationships between flood distribution and each related parameter. In calculation of the Flood Hazard Index, a summation of values of each parameter's frequency ratio is used to produce a flood prone area, as seen in Equation 1:

$$Fr_i = \frac{N_{(Si)}/N_{pix(Ni)}}{\sum N_{pix(Si)} / \sum N_{pix(Ni)}} \quad (1)$$

Where; $N_{(Si)}$ is the number of pixels of flood area in a certain parameter class; $N_{pix(Ni)}$ is the number of pixels in a certain parameter class; $\sum N_{pix(Si)}$ is the total number pixels of a flood area in a certain parameter class; and $\sum N_{pix(Ni)}$ is the total number of pixels in a certain parameter class.

The higher pixel values of the flood hazard index are the higher hazard to flood occurrence, and the lower values are the lower hazard to flood occurrence.

4.2. Flood Analysis

Regarding the results from the spatial analysis, several flood areas will be used to perform a rainfall analysis. For the temporal analysis, rainfall and stream data from the flood report will be calculated to make several time series showing the circumstances of the flood event described by the respective flood reports.

The rainfall threshold of a flood based on the cumulated volume of antecedent rainfall during a storm event resulting in a critical water stage (or discharge) at a specific river section are estimated by hydrological modelling [7,8]. Analysis is undertaken of rainfall threshold related to rainfall rate, duration and inundation area for the river system critical state. Figure 2 illustrates the steps of the rainfall threshold evaluation procedure.

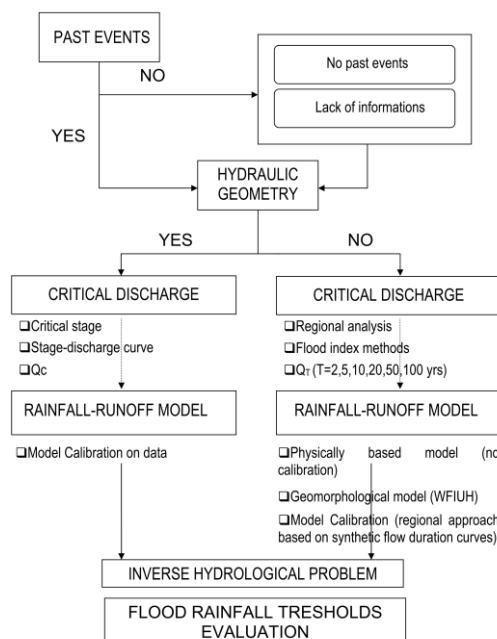


Figure 2. Flood Rainfall Threshold Evaluation [9]

4.3. Hydrodynamic Modelling

Hydrodynamic modelling is a common model in flood assessment, due to temporal data for numerical modelling using Saint-Venant equations becoming more accurate, and the detailed data collection of river investigation has been improved in areas such as high resolution topographic, rainfall, water level, river velocity and water discharge. Several studies of the commercial tools of the hydrodynamic model using HEC_RAS for 1D river modelling [10], MIKE 11[11] and SOBEK [12]. For 2D overland flow, modelling had been developed via TUFLOW, and RMA2 [12]. The integration of two or more hydrodynamic models to improve the modelling capability had been studied by Smith and Rowland [13].

Flood inundation simulation in dynamic system software depends on depth values at the cross section of the river. The hydrological model approach uses the Saint-Venant equation for open channel flow. The Saint-Venant equations are two coupled partial derivative equations.

$$\frac{\partial A(x,t)}{\partial t} + \frac{\partial Q(x,t)}{\partial x} = 0 \quad (2)$$

$$\frac{\partial A(x,t)}{\partial t} + \frac{\partial}{\partial x} \left[\frac{Q^2(x,t)}{A(x,t)} \right] + gA(x,t) \left(\frac{\partial Y(x,t)}{\partial x} + S_f(x,t) - S_b(x) \right) = 0 \quad (3)$$

$$S_f = \frac{Q^2 n^2}{A^2 R^{\frac{4}{3}}} \quad (4)$$

Where, Q is the total flow down to reach; A is the cross sectional area of flow in channel (A_c) and floodplain (A_f); P is wetted perimeter; R is the hydraulic radius (A/P); n is the Manning roughness value; and S_f is the friction slope.

4.4. Decision Model

The decision making process involved making choices regarding to appropriate mitigation, resulting in an effective outcome in managing the wide impact of the flood. An Analytical Hierarchy Process (AHP) model technique will be developed for the evaluation of user preferences for many criteria to adapt to the adverse impact of flooding. The Analytic Hierarchy Process (AHP) relates the decision with a pairwise comparison of alternative adaptation, based on judgements of the decision maker to derive priority scales. As Saaty [14] contends, decision-making is an organized technique in order to generate priorities which breaks down the decision into several steps:

1. Identification of problem and knowledge.
2. Goal of decision as the top of a decision hierarchy, then objectives from a various perspective, via the intermediate to the lowest level
3. Set of pairwise comparison matrixes is developed by valuation of each element at upper level and the level immediately below.
4. Comparison between evaluation of the priorities in the level immediately below for every element used to obtained priorities. A summation weighing up the values of each element in the level below will produce a general priority. The weighing process was continued and added to, until reaching final alternative priorities in the bottom most level.

5. Conclusion

In conclusion, an effective assessment of flood risks integrates spatial and temporal factors in the decision modelling approach. The dynamic and spatial flood model involved the analysis of floods in

terms of area and time. An availability of comprehensive flood assessment studies can assist a decision maker in restructuring the method design adaptation strategies at a local level. It is essential to develop a flexible and well-structured method which enables the collection of information to design the most effective adaptation in reducing the impacts of flooding. An integration of Geographic Information System (GIS), system dynamic (SD) and multiple criteria decision aid modelling approach provides a powerful methodology to assist the decision maker in selecting the appropriate adaptation strategies for the prevention of flooding in the future.

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