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Decision-Making Framework With the Application of Cost-Benefit Analysis for Flood Mitigation Management

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Abstract: Flood events in socioeconomic areas can cause various negative effects. Flood protection has traditionally attracted a lot of attention, leading to significant expenditure for the Government. This paper will demonstrate how to apply Cost Benefit Analysis (CBA) and to assist decision makers in river flood investment. CBA is measured in terms of monetary value using the societal and environmental benefits and costs of flood mitigation projects. The methodological approach for this paper is combining both engineering and economic analysis. Flood map and mitigation measures generated from hydrodynamic modelling will be evaluated using CBA. The conclusion discusses aspects of CBA related to flood mitigation projects. If benefits outweigh the costs, the project is beneficial and will result in an increase in economic well-being. A decision-making framework for flood mitigation management is later developed combining both engineering and economic analysis. Since resources and budget are very limited, the framework can assist decision makers while making flood management decision.

Keywords: Flood management; Cost Benefit Analysis; Decision making

1. Introduction

Floods are not only the most expensive natural disaster in the world, but they have also claimed many lives and property. Floods are natural meteorological and hydrological phenomena affecting economic and social balance. Existing human economic activities that harm the earth's ecology will create threats to sustainability issues. Previous research has shown that to achieve sustainable development, environmental investments should be evaluated in terms of their costs and benefits [1]–[3]. Implementing flood mitigation projects that are always on demand requires the decision makers, often from the government, to have appropriate methods for deciding priority projects that are value for money in a sustainable approach.

When incorporating socioeconomic areas into a cost-benefit analysis (CBA) for flood mitigation measures, it is also important to consider how the proposed flood mitigation

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solution will impact the community's various social and economic aspects. In practice, most investments in flood prevention are made after severe losses. As a result, it is critical for decision makers to understand that every alternative accessible for sustainable floodplain development has an opportunity cost that must be spent for social and environmental purposes.

Therefore, this paper aims to assist the decision makes in flood management throughout the decision-making process by selecting the optimum flood mitigation measures. The selection of flood mitigation measures is only based on the lowest and cheapest cost. This paper will also contribute research on evaluation and assessment in managing flood mitigation investments by integrating both hydrodynamic modelling and economic assessment using CBA to assess flood mitigation measures for solving engineering problems. This ensures that decisions relating to flood mitigation projects are made sustainably, economically, and holistically with the application of hydrodynamic modelling and CBA as the decision-making tools.

1.1 Definition of Flood Mitigation

Natural floods occur due to intense rainfall and excess runoff, leading to river flooding. The situation will worsen when intense rainfall is combined with high tide events. Urban areas are the most affected when natural permeable surfaces are removed and replaced with impervious surfaces like pavements, concretes and roofing materials such as metals and tiles. High intensity rain can cause flooding when these non-permeable surfaces increase runoff volume as water cannot infiltrate the ground. This leads to higher runoff volumes compared to permeable surfaces causing flooding [4]. Flood mitigation refers to the strategies and measures taken to reduce or prevent the impact of flooding on people, property, and the environment. Flood mitigation measures include structural flood defence mitigation systems such as dikes, retention basins, river channelization and improvement works, flood diversion channel or tunnel, pumps and flood gates [5]–[7]. Therefore, flood mitigation measures should not only aim to reduce flood risk but also to enhance the floodplain's environmental, social, and economic assets.

Hydrodynamic modelling is an engineering analysis that aims to understand river conditions. The modelling simulates flood data for flood risk assessments and mitigation strategies. To understand flood trends in various scenarios, hydrodynamic modelling is employed to analyze specific rainfall design occurrences over various flood return periods. [8]–[11].

1.2 Application of CBA in Flood Management

Cost-Benefit Analysis (CBA) approach evaluates resource allocation and investment in flood mitigation management. It is to ensure that limited resources allocated to projects will provide the best results in terms of operational effectiveness and long-term viability [12], [13].

Value-for-money flood mitigation projects should be prioritised, and cost savings from capital and operating expenses can assist decision makers in determining the financial feasibility of mitigation strategies [1], [3]. Flood management decision makers can make informed decisions that maximize value for stakeholders while also optimizing financial performance by conducting a thorough CBA. CBA determines how much money should be invested in river flood management based on whether the project's benefits outweigh the costs. The cost includes both project and maintenance costs. Benefits include reduction of flood damage, societal, and environmental costs. If the benefits outweigh the costs, the project is a go and will increase economic well-being.

1.3 Decision Making Framework

Deciding to invest in flood mitigation projects, the government has to make sure that lives lost and property destroyed after flood events is optimized as well as to minimize the estimated expenses. As to support the decision making process, a decision-making tool will enable to carry out an effective decision-making technique in order to attain project objectives [14]–[16]. The application of hydrodynamic modelling and CBA in flood mitigation management will not only communicate the efficiency and effectiveness of flood mitigation measures but it will also translate their economic relevance.

The engineering and economic analyses conducted for this paper will be combined to develop a framework for decision-making on flood mitigation management. Hydrodynamic modelling using Infoworks Integrated Catchment Modelling (ICM) is combined with cost-benefit analysis to identify efficient and cost-effective flood mitigation measures.

2. Methodology

The methodological approach chosen for this paper is through hydrodynamic modelling as the input for the decision-making process that looks into the cost and benefit of it using CBA [8], [9], [13], [17]–[22]. CBA is performed to calculate present value of both benefits and costs with a discount rate. The discount rate used for CBA of flood damage mitigation is 4% [23]. The economic analysis of the benefits and costs of the selected mitigation measures is calculated by comparing the differences in damage from floods, society, and the environment. The costs consist of project cost and maintenance while benefits look into flood damage cost, societal and environmental costs. The benefit-cost ratio (B/C) will analyze for the selected flood mitigation measures. A project is considered beneficial if the benefits (B) surpass the costs (C).

The following equations represent the benefit and cost of implementing flood mitigation measures [24]:

$$CBA = \begin{cases} \text{Yes if } \frac{B}{C} > x \\ \text{No if } \frac{B}{C} \leq x \end{cases} \quad (1)$$

$$NPV_B = \sum_0^T \left(\frac{1}{1+r}\right)^t b \quad (2)$$

$$NPV_C = \sum_0^T \left(\frac{1}{1+r}\right)^t c \quad (3)$$

Equation 1 states that a project is beneficial if its lifetime discounted benefits (B) are more significant than its lifetime discounted costs (C). Equation 2 and Equation 3 shows present values are made by multiplying the benefits and costs of a certain year with a discount rate $(1/(1+r))^t$ where t is a function of time and r is the discount rate [23]–[25].

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2.1 Study Area

The paper area is located in Sungai Pinang catchment, which is in Georgetown, North East District of Penang, Malaysia. It is a rapidly urbanizing region along the east coast of the Penang Island. Peninsular Malaysia experienced the worst flood in 2017, with a death toll of at least seven individuals in the northern countries of Penang and Kedah [26], [27]. Penang within the district of Barat Daya and Timur Laut recorded heavy rain from 4th November 2017 to 5th November 2017, with a total of 296 mm rainfall within 24 hours with the depth of flood range between 0.3m - 2.4m [28]. The flood that struck the state of Penang in 2017 is believed to have cost RM 200 million in damages. Figure 1 demonstrates the flooded city of Georgetown during the major flood event on 5th November 2017. It is reported that 7,412 people were evacuated from their homes in Penang during the incident. The flood and storm are described as the worst in Penang's history. Department of Irrigation and Drainage (DID) took immediate action, which resulted in approved allocation by the Federal Government to address the flooding issues. The Sungai Pinang Flood Mitigation Project, approved by the Ministry of Water and Natural Resources in 2017, mainly focuses on flood mitigation in Sungai Pinang's downstream section.

Fig. 1 – The flooded city of Georgetown during the major flood event on 5th November 2017

2.2 Elements in CBA

Sungai Pinang Flood Mitigation Project is designed for a 100-year ARI, and the chosen mitigation measures are river improvement and floodwall. The river improvement work involves canalisation such as river deepening and widening. The costs and benefits are expressed in Malaysian Ringgit (RM) at a 4% discount rate. The benefit-cost ratio (B/C) is the ratio of the benefits derived from a mitigation measure to the total cost of its construction.

Costs are the amount of investment required to fully operationalise mitigation measures, which includes construction and maintenance of it. Data regarding the construction and maintenance of the mitigation measures for river improvement and floodwalls are collected from DID. The benefits considered under the flood risk management measures are flood damage cost and societal and environmental cost. Flood damage costs are costs that are directly related to reducing flood damage and economic activity [24]. The price of flood damage will refer the Flood Damage Assessment Report 2012 done for Sungai Pinang Basin by DID.

Social benefits for this paper looks into the potential amount of compensation and flood assistance fund paid to flood victims by the Government [29], [30]. Social welfare represents the government's assistance to flood victims to lessen the financial burden of the disaster. Most governments prefer cash compensation because it is more straightforward and quicker to distribute logistically and administratively.

The environmental benefit is estimated by comparing the cost of past river restoration projects. The estimates are measured for the length of the river and expressed as the cost per kilometre of river restoration. Environmental expenses include those associated with project planning and design, river widening and deepening, river landscape and land acquisition costs [31], [32]. Table 1 demonstrates a variety of flood mitigation project impacts that can be considered costs or benefits. It provides a general description of variables that can be used to determine key benefit and cost criteria. These variables are references made based on academic research on CBA for flood risk zoning regulations [24].

Table 1 – The benefits and costs considered for flood mitigation projects

	Benefits	Costs
Flood damage assessment	Reduced flood damage and economic activity. The flood damage is due to the average loss value for each type of damage.	• Project cost • Maintenance cost
Societal cost	Reduced the amount of compensation and flood assistance fund, paid to flood victims by the Government.	
Environmental	To reduce the river restoration costs causing negative changes in water quality for Sungai Pinang by undertaking river improvement works.	

3. Results and Discussion

This paper aims to assist flood management decision-makers in assessing CBA of flood management before deciding on a flood mitigation project.

3.1 CBA in Flood Management

The flood event referred to for this paper was from 3rd November 2017 to 6th November 2017, with a total flood area of 6.11 km2 and a flood depth of 1.2m and above.

The CBA results are reported in Table 2. They indicate the total cost and total benefit of flood mitigation measures for river improvement and floodwalls. The NPV of benefit and cost is calculated with the discounting rate, r, of 4% over 100 years for the function of time, t, using formulas (2) and (3). The score table shows that the B/C ratio is 1.00. A project is beneficial if the benefits outweigh the costs when it generates an increase in economic welfare, and a lower-benefit activity is otherwise unattractive. Therefore, if the government's decision to proceed with the project is based on the cost-benefit analysis, flood mitigation measures resulting from hydrodynamic modelling will be adopted.

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Table 2 – Cost and benefit for flood mitigation measures of river improvement and floodwall

Total cost (Million RM)	Total benefit (Million RM)	B/C ratio
153	Flood damage: 131 Societal: 7 Environmental: 16	1.00

NPV at discounting rate of 4% over 100 years

3.2 Decision Making Framework for Flood Mitigation Management

A decision-making framework is developed by integrating hydrodynamic modelling with cost-benefit analysis. The framework is divided into 4 stages: planning, engineering analysis, economic analysis and evaluating results. Stage 1, the planning stage, identifies flood damage data during a certain flood event. Flood data is required for several discharges in order to establish the extent of existing floods and water depths across the affected area. The data will then be analysed and proceed to the design stage. The hydrodynamic model will simulate flooding situations with selected flood protection levels. Stage 2 is performing the engineering analysis to generate the impact of the hydrological analysis for this paper. The analysis will involve modelling and calculating flood levels and flood flows and finally generating a flood hazard map for the selected flood mitigation measures. Following the completion of the hydrological and hydraulic analysis, the benefit of a flood mitigation project is calculated by the differences in damage from floods, society, and the environment. Stage 3, the economic analysis, will calculate the present value of benefits and costs with a discount rate. Present value is the present value of future advantages that have been costed, creating a uniform reference point for comparing costs and benefits. It is the consequence of a quantity of money worth investing to generate future annual benefits. The final stage, Stage 4, is the evaluation of the result by comparing benefits and costs for the selected flood mitigation measures. If benefits surpass costs, the project is considered beneficial. The method used for the decision-making framework for flood mitigation is by combining hydrodynamic modelling with cost-benefit analysis. The basic approach used in this framework starts with Stage 1 until Stage 4, as in Figure 2.

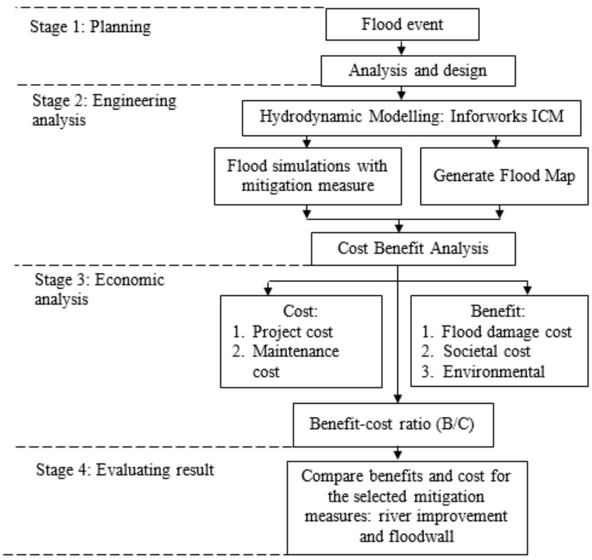

Fig. 2 – Decision Making Framework for Flood Mitigation Management

4. Conclusion

In accordance with the objective of this paper, the decision-making framework is developed by combining engineering analysis and Inforworks Integrated Catchment Modelling (ICM) with CBA. The sequences of Stages 1-4, as shown in Figure 1, have formed a flood mitigation management decision-making framework. This has resulted in the decisions relating to flood mitigation projects made sustainably, economical and holistically.

A systematic approach is required to create consistent and credible flood economy estimates for essential decision-making. For a developing country like Malaysia, flood damage is severe. Flood danger is rising in frequency, area, and population. Critical flood catastrophe decisions must be backed by a detailed cost-benefit analysis that appropriately reflects the national and local circumstances. A thorough and all-encompassing strategy is needed to assess flood economics reliably. This will also help the Federal and State governments accurately analyse and distribute resources for the public good.

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