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Cost-Benefit Analysis of Mobile Flood Wall Barrier's Implementation on Government School's Compound

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Abstract: Floods have caused disturbances worldwide, including in Malaysia, and these disturbances can be exacerbated by the global effects of climate change. Mobile floodwall barriers (MFWB) on a building or its compound have emerged as a possible solution to reduce the impact of flooding, particularly low to moderate floods (i.e., floods approximately less than one meter high). This study analyzes how MFWB can effectively reduce flood impacts in terms of costs and risk reduction benefits. The effects of MFWB are analyzed based on what-if scenarios combined with hydrology and hydraulic simulations of floods at SK Sri Kembangan Primary School in Serdang, Selangor, Malaysia. The results show that in all tested scenarios of MFWB wet-proofing performance, achieving a return on investment is difficult when the price of MFWB is higher than the actual costs (approximately RM2,000 to RM3,000 per panel of one meter in length). It is advisable that costs are lowered to ensure a return on investment. At the same time, MFWB functionality needs to be ensured, with minimal intrusion of floodwater.

Keywords: Cost-benefit analysis, property-level protection, Flood Management, Flood risk, decision making

1. Introduction

Floods have caused disturbances, damaging property and assets, and disrupting human livelihoods. Malaysia is susceptible to floods due to the global and local effects of climate change. Increased rainfall occurrences will continue to threaten those living in low-elevation areas [1]. Although predictions of flood events are uncertain, the resulting impacts would be detrimental, making adaptation efforts to reduce flood risk essential [2]. Residential sectors have reported the most significant flood losses [3], although other sectors, such as agriculture and industries, are also vulnerable [4].

In recent years, building-level protection has emerged as a possible solution to reduce the impact of floods, especially low to moderate ones (i.e., floods approximately less than one meter high). Building-level protection refers to adaptation measures that target protection at the building level. It prevents targeted buildings and/or their compounds from being 'sealed' or partially sealed with physical barriers, even when the surrounding area is inundated. One advantage of building-level protection is that it allows the floodplain to function by being inundated during extreme weather conditions, avoiding the need to relocate buildings exposed to flooding by using floodplain barriers [5].

Structural building-level protection measures can effectively serve as a second layer of protection against flood intrusion. Their effectiveness has been explored and reported in technical papers and government reports from other countries. For example, studies have investigated the post-installation effectiveness of building-level measures in the UK [6]. These studies evaluated 40 post-installation reports, engaged with over 80 stakeholders, and interviewed over 50 residents to produce a report on the cost-effectiveness of property-level protection for residential buildings. A study by [7] also found that building-level measures are more cost-effective in less densely populated areas (i.e., areas with fewer buildings).

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In Malaysia, the adoption of building-level measures is driven more by individual preference than by authorities' enforcement efforts. Experiences with frequent floods have led people to develop creative solutions to prevent their houses from flooding. For example, some have built elevated concrete barriers around their properties. The investment return on building-level measures in Malaysia is not yet known, but theoretically, it is much cheaper than relocation and resettlement. To support the development of building codes or the adoption of such measures, research is needed to provide evidence of their investment performance in the Malaysian context. This study aims to investigate the cost-effectiveness of investing in flood wall barriers in Malaysia. We consider a product by JPS Malaysia and its implementation on a school building's compound. The JPS flood wall barriers installed are NADI type 2 and NADI type 3 (NADI2 and NADI3), which are explained in more detail in Section 2.3.

1. Study area and methodology

This study focuses on Sekolah Kebangsaan Sri Serdang (SKSS), a government school located upstream within the Kuyoh River basin, to analyze the cost-effectiveness of MFWB. The school is a government primary school and **has reportedly** experienced frequent floods since its operation in 1985. It has been identified as potentially one of the flood hotspots in the Petaling district of Selangor. The state of Selangor covers an area of approximately 8158 km² [8] and is situated in the central-western region of Peninsular Malaysia, and the rivers in the state flow towards the Straits of Malacca. Similar to other regions in Malaysia, Selangor is subject to a tropical climate characterized by occasional rainfall, which may be attributed to global atmospheric circulation patterns and influenced by localized convective processes. Fig. 1 presents a tabulation of over 200 subbasins within Selangor.

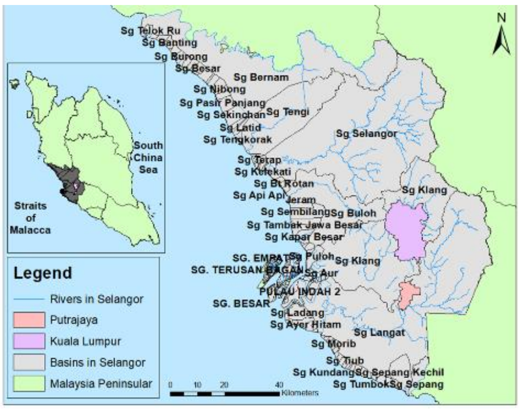

Fig. 1 - River Catchments in Selangor

Table 1 presents flood depth data recorded from historical flood events, as obtained from the DID's flood reports spanning the years 2016 to 2020. These reports indicate that floods have caused damage to SKSS buildings, potentially affecting the interior and contents of classrooms, a prayer hall, and the surrounding landscape and garden. Based on direct communication with some teachers during a visit to the school, the estimated damage from a single flood event could be as high as RM25,000. It was mentioned that during periods of heavy rainfall, the school's parking area tends to flood rapidly, which could create challenges in moving vehicles and students.

Table 1. Flood depths in SKSS based on flood reports

Date/Year	Flood depth
4 Sept 2012	0.5m - 1m
21 Apr 2014	0.1m - 0.3m
2 Apr 2019, 1 June 2019 and 9 Oct 2019	0.1m – 1.0m
1 Nov 2021	0.1m-1.0m

The area is recognized for its low-lying terrain, which likely contributes to the accumulation of runoff during flood events. Upon examination of the elevation map, it appears that the topography of SKSS is lower in elevation compared to its surrounding areas. The low topography of the school and the outdated design of channels and drainage systems may have contributed to the overflow of local drains. Furthermore, its location downstream of the subbasin has resulted in insufficient time for runoff to be conveyed out from the Kuyoh River basin and the accumulation of runoff volume inundating the area.

To mitigate the inundation of floods in the area, pumps have been installed at the school to be operated during flooding. However, there have been reports of incidents of non-functionality of the pumps, possibly due to rubbish blockage and insufficient time for the pumps to be operated in time. Damage to the school buildings might be reduced by considering flood wall barriers.

The school has four locations with wide openings that **may** require MFWB: two openings for pedestrian entrance and two for vehicle entrance (Fig. 2). It is important to note that this study **primarily focuses** on simulations of flooding using hydrodynamic modeling and considers scenarios of protection level, rather than on specific actual events or the processing of empirical data.. The subsequent section will present the flood simulation incorporating rainfall-runoff modeling.

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Fig. 2: Location of the school from the aerial view (The upper and middle picture from Google Earth) and the last three main locations for MFWB.

1.1 Design rainfall and runoff coefficients

The rainfall-runoff model and the flood extent at SKSS were simulated using XP-SWMM software. XP-SWMM is capable of simulating runoff generated from designed storm events in urban watersheds, including the movement of runoff through pipelines and channels. Important data for the hydrological modeling was established, using iFSAR DTM for ground elevations and catchment delineation. Then, a georeferenced base map image for the SKSS area was overlaid to provide high-quality images of buildings and roads in the river basin. Twelve sub-catchments were delineated, based on the drainage system indicated by the map image. These sub-catchments covered Sri Serdang town, Faculty of Engineering UPM, Masjid UPM, Islamic and Chinese cemetery, and Sri Serdang Lama until the Institute of Bioscience UPM.

The design storms were obtained from the intensity-duration-frequency curve (IDF) published in the Urban Stormwater Management Manual (MSMA) [9] (Fig. 3). The time of concentration from the upstream Kuyoh river basin to the SKSS area was computed based on available land and topographical information. The SKSS topography, as provided by iFSAR, appears to have served as the reference for the flow path analysis. This study involved individual simulations of flood inundation for the 5, 10, 20, 50, and 100-year flood events. Table 2 presents the design rainfall information for these return periods, indicating that the rainfall intensity ranges from approximately 95 mm/hour for a 5-year return period to around 180 mm/hour for a 100-year return period.

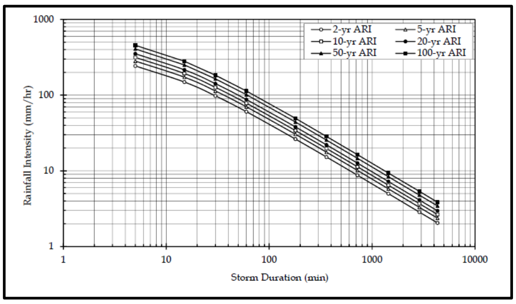

Fig. 3 - IDF curve for Setor JPS Kajang

Table 2 - Rainfall Intensity for sub-basin of SKSS

Return Period (Year)	Time of concentration (min)	Rainfall Intensity (mm/hr)
5	21.24	195.05
10	21.24	245.06
20	21.24	307.89
50	21.24	416.33
100	21.24	523.08

The rational method (Equation 1) was applied to simulate the excess rainfall. Factors such as the drainage area, the runoff coefficient, and rainfall intensity were considered for the configuration of the rational method. The runoff coefficients were determined for each subbasin based on the land use information suggested in [9].

$$Q = \frac{C.i.A}{360} \qquad (1)$$

where,

Q= Peak flow (m³/s)
C= Runoff coefficient
i = Average rainfall intensity (mm/hr)
A= Drainage area

To continue with the hydrodynamic modeling, a georeferenced base map image for the SKSS area was overlayed to provide a high-quality image for building distribution at the SKSS area. A modified rational method was used to simulate the hydrograph of the peak runoff. Other inputs to the XP-SWMM model for the simulation include infiltration loss. Furthermore, a ground survey was undertaken to obtain information about the drainage system and its characteristics within the SKSS. The ground survey included measuring the invert level, drain size, and ground elevation to use as input for the hydrodynamic modeling. According to the survey, the average invert in front of SKSS was found to be 1.2 m in width and 1.6 m in depth. For drainage systems in other sub-catchments, the depth appeared to vary from 1 to 2 meters.

For the hydraulic simulation in XP-SWMM, nodes and links were established within the sub-basin.. The simulation applied the dynamic wave equation to calculate the maximum flow along the pipe driven by the storm event. The spread of the flow over the 2D region in the model used the Saint-Venant equations, commonly referred to as dynamic wave routing, and the conservation of the Continuity, Equation 2, and Momentum, Equation 3, was automatically executed in XP-SWMM.

Continuity equation:

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

Momentum equation:

$$\frac{1}{A}\frac{\partial Q}{\partial t} + \frac{1}{A}\frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + g\frac{\partial y}{\partial x} - g(S_o - S_f) = 0 \qquad (3)$$

where:

Q = discharge through the channel
A = Area of cross-section of flow
y = depth of flow
S_o = Channel bottom slope
S_f = Friction slope

The modeling work was repeated for 5, 10, 20, 50, and 100-year events for the purpose of risk analysis. These storm events, in return, resulted in approximately 0.35, 0.41, 0.45, 0.64, and 0.86 m maximum flood depths at SKSS (further details are provided in the results and discussion section).

1.2 Flood damage curve

The DID's Updating Flooding and Flood Damage in Malaysia report [10] was utilized to represent the susceptibility of an institutional building in terms of economic losses. Various studies have employed this equation for case studies in Malaysia (e.g., [11]). For an educational building, the UCFDAA suggests a mean damage that can be used to estimate the possible damages. UCFDAA also suggests a damage function that utilizes two covariates: flood duration and depth. The function was reported to be derived from multiple regression over data from the questionnaire, thus providing a set of fixed coefficients in the damage function. The co-variates determine the damage factor of predicted monetary losses (Equation 4). The mean flood duration and the mean flood depth for the damage equation are suggested by UCFDAA as 2.45 days and 0.76 m, respectively.

For the calculation of flood damage for SKSS, the flood duration was set to be 6 hours, as indicated by flood reports. Meanwhile, the flood depth utilized was based on the values obtained from the XP-SWMM flood simulation.

$$\text{Total damage factor} = (Depth\ in\ metre - Mean\ Depth)\ X\ 0.32) + (Duration\ in\ days - Mean\ Duration)\ X\ 0.08) + 1 \qquad (4)$$

1.3 MFWB costs and performance

At SKSS, there were four locations where NADI was installed: two at the pedestrian entrances and another two at the vehicle entrance. The former utilized NADI2 (a single panel), while the latter used three panels of NADI3 at each location (linked by steel poles). The price per NADI panel was ontained from NAHRIM's report, and the total MFWB costs for SKSS were computed based on the number of panels needed for each opening (Table 3). The costs of MFWB included capital costs (incurred in the first year of implementation) and a maintenance cost set at 1% of the capital costs incurred each year for 20 years over the appraisal years. The design life of MFWB is typically considered to be 20 years, according to international reports [12]. The MFWB would likely undergo replacement once its design life ends.

A discount rate of 3.29% for Malaysia (i.e, according to [13]) was used to convert the costs over the appraisal years then to present value. Cost scenarios were considered to account for potentially higher and lower investment costs, for example due to additional measures to support full-proof, or due to different costs of MFWB (Table 4).

Table 3 - MFWB panel cost

	Price per panel (RM)	Number of locations for installation	Unit panels per location	Current cost (RM)
NADI2	3,357	2	3	24,714
NADI3	2,286	2	1	

Table 4 - Costs for MFWB installation and maintenance in SKSS

Scenario of costs	Costs (RM in present value)
Current cost	27,268
15% less cost	23,178
50% more cost	40,902
Triple current price	81,804
Quadruple current price	109,072

Three scenarios of MFWB physical effectiveness, sometimes called wet-proofing (allowing water to minimally enter the residential buildings), were also considered to reflect the reality of the potential failure of the system. The conditions considered included 20%, 80%, and 100% wet-proofing performance, where the lowest percentage represents the smallest amount of water entering the vicinity from outside. The varied assumptions account for the fact that the functionality of MFWB might not always be perfect due to imperfect installation or product features during floods.

The protection level in the case of MFWB was considered numerically. The assumption was that protection to the building is up to 0.5m from the ground in the case of complete protection. Flood water was assumed to potentially intrude and inundate the protected vicinity for the considered range of physical effectiveness. The effects of physical ineffectiveness were modeled numerically by lowering the maximum flood depth with full protection by a certain percentage. Here, a selection of 20%, 80%, and 100% proofing levels was made.

1.4 Flood risk and cost-benefit analysis

Flood risk estimation integrates the probability of floods and the expected damage. It can be expressed in summation terms (Equation 10) and quantified as expected annual damage (EAD), which has been widely adopted (e.g., [7]). The risk estimation essentially approximates the area under the damage-probability curve.

$$\boldsymbol{Risk} = \sum_{i=1}^{N} (p_{i+1} - p_i) \bullet \frac{(D_{i+1} + D_i)}{2} \qquad (10)$$

p represents the probability of a discharge scenario occurring given by the return period, i denotes the flood event and D_i represents the flood damage of the i flood event.

Flood risk was quantified and compared to the risk without MFWB for each case considered in this study. The difference between the risk with and without MFWB indicates the benefit of risk reduction, which represents the monetary annual benefit of implementing MFWB over the appraisal period. The assumption of yearly constant benefit is based on the premise of insignificant change in the probability of flooding each year. The economic benefit, therefore, takes into accounts for the physical performance of MFWB. The subsequent step was to compare the benefits and costs of MFWB adoption in present values. For this purpose, the discount rate was also applied.

2. Results and discussion

Upon investigating the results from the flood simulation, the highest flood depth for the 100-year return period reached 0.86 meters, though a smaller depth was observed over the area. Meanwhile, the maximum flood depth for the 5-year return period was 0.35 meters. Fig. 4 shows the flood map for 100-year return periods over SKSS and surrounding area.

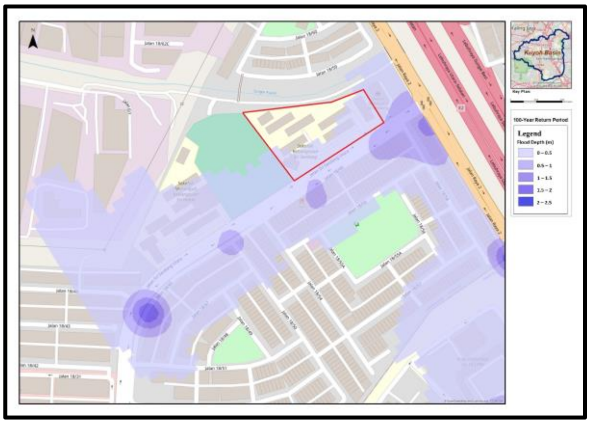

Fig. 4 - Flood map SKSS for a 100-year return period

Table 5 presents the flood depth and flood damage for different MFWB scenarios. The findings of the simulation suggest that the MFWB may mitigate the flood depth for 5-year, 10-year, and 20-year return periods. On the other hand, MFWB may not be able to prevent flood depth for return periods of 50-year and 100-year return periods since the maximum flood depths appear to exceed the height of MFWB.

Table 5 - Flood depth and flood damage at SKSS

Scenario	**Return Period**	**5**	**10**	**20**	**50**	**100**
Without MFWB	Flood Depth (m)	0.35	0.41	0.45	0.64	**0.86**
	Flood Damage (RM in Thousand)	358.58	367.72	373.82	402.78	**436.31**
MFWB wet proofing up to 20% protection)	Flood Depth (m)	0.28	0.33	0.36	0.64	**0.86**
	Flood Damage (RM in Thousand)	347.91	355.22	360.10	402.78	**436.31**
MFWB scenario (80% protection)	Flood Depth (m)	0.07	0.08	0.09	0.64	**0.86**
	Flood Damage (RM in Thousand)	315.90	317.73	318.95	402.78	**436.31**
MFWB Scenario (100% Protection Up to the Protection Level)	Flood Depth (m)	0.00	0.00	0.00	0.64	**0.86**
	Flood Damage (RM in Thousand)	0.00	0.00	0.00	402.78	**436.31**

2.1 NPV and BCR

The net present values (NPV) and benefit-cost ratio (BCR) for all conditions are shown in Table 6, Table 7, and Fig. 5. The 100% physical efficiency of MFWB appears to yield highest NPV when the costs of MFWB are 15% less than the actual considered costs. Nonetheless, the 100% MFWB workability might be difficult to achieve in practice. Shifting to the 80% MFWB efficiency, results indicate that the NPV remains positive at a cost-beneficial performance. However, the NPV tends to decrease as the costs of MFWB increase. As for the 20% protection efficiency scenario, it seems there is no positive return despite the reduction of costs. Hence, adopting MFWB with 20% protection efficiency or less would likely represent a less favourable investment for the study area.

The results suggest that it is vital for the MFWB to withstand water (near to full proofing) with minimum investment costs for it to be cost-beneficial. Regarding BCR, complete protection at a 100% physical resistant level appears to yield the highest, i.e., 7.49, three times more than the current cost. Meanwhile, the BCR remains acceptable, i.e., 4, at 80% wet-proofing condition under the current estimated investment cost. However, for a higher than the current estimated price, the only worthwhile investment might be when the price reaches 50% more than the current price.

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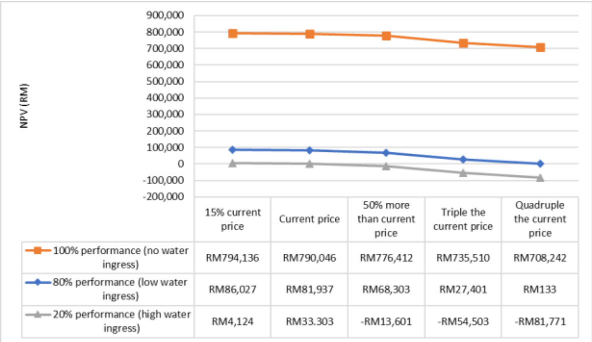
Table 6 - Net-present value (RM)

The considered scenario (cost considered in present value)	20% Protection	80% Protection	100% Protection up to the protection level
15% less than the current cost (RM 23,178)	4,124	86,027	794,136
Current estimated cost (RM 27,268)	33	81,937	790,046
50% additional cost (RM 40,902)	-13,601	68,303	776,412
Triple of the current price (RM 81,804)	-54,503	27,401	735,510
Quadruple of the current price (RM 109,072)	-81,771	133	708,242



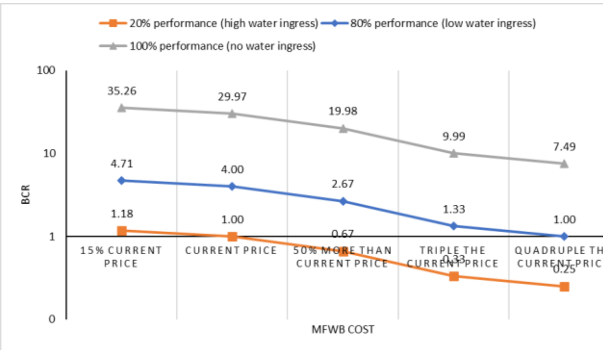


Fig. 5 - The net present values (NPV) and benefit-cost ratio (BCR) for different cost possibilities of MFWB.

Table 7 - Benefit-cost ratio for SKSS

The cost considered/ Scenario	20% protection against water ingress	80% protection against water ingress	100% protection against water ingress
15% less cost (RM 23,178)	1.18	4.71	35.26
Current estimated cost (RM 27,268)	1.00	4.00	29.97
50% additional cost (RM 40,902)	0.67	2.67	19.98
Triple the current price (RM 81,804)	0.33	1.33	9.99
Quadruple the current price (RM 109,072)	0.25	1.00	7.49

The study suggests how MFWB can potentially be effective and conversely, regarding monetary cost, benefits, net present value, and benefit-cost ratio. The following lists the main findings from the study.

1) MFWB may only be effective for relatively frequent events (in this case, up to 20-year return period event), but likely not for infrequent events (for example, 50 and 100-year flood events).
2) 100% workability of MFWB during floods could yields a good return on investment. It is pertinent that the materials and design of MFWB should ideally prevent water intrusions while maintaining its workability.
3) 20% and 80% wet-proofing conditions of MFWB during floods might still offer a return on investment, but only if the costs of MFWB are low.
4) In most circumstances of MFWB functionality, it may be difficult to have a return on investment when the price of MFWB is higher than RM2,000 to RM3,000 per panel of one meter long. The costs should ideally be at the lowest possible yet function effectively during floods to conform to return on investment.

One potential challenge for MFWB to be functional when needed could be the participation of people in handling the measures during floods. Because natural floods may be relatively rare, human consciousness on the way building-level protection should be handled, and mounted during floods could potentially be jeopardized. Furthermore, building-level protection with systems designed to be automated during floods might help improve its physical effectiveness. Proper guidelines and training schemes should be considered, planned and executed to reduce incompetence. The success of the system likely requires institutional involvement and centralized coordination. This way, flood risk could potentially be reduced with building-level protection, at least for frequent and low-depth floodings.

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