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Dam Break Analysis of Batu Dam Using Hec-Ras

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Abstract

In Malaysia, dams are commonly built because they benefit the local community in several ways, especially through agricultural production and flood control. Nevertheless, an unexpected containment breach could result in the loss of life and property in a populated area downstream due to its huge potential energy reservoir. Dam break event simulations are essential for identifying and mitigating risks associated with possible dam breaches. Batu Dam has the highest percentage of the population at risk (PAR) and most likely exposed to the flood disaster due to dam break. From flood boundary maps, it was estimated that 78% of residential areas would be affected if a dam break disaster occurs. From the simulation, the maximum depth can reach up to 18 m with an estimated flow speed between 0.2 m/s – 3 m/s. At these depth and flow speed, people may lose strength and unable to control themselves in flood and would cause death and injury. Flood arrival time took 15 to 22 hours for flooding to arrive downstream with a maximum flood depth of 5.07 m at Persiaran Jasa Utama and the highest depth of 12.62 m at Kampung Baru Batu Caves with flood velocity between 1.60 m/s to 1.46 m/s. Analysis and simulation of embankment dam breach events and the resulting floods are crucial for distinguishing and mitigating dangers from potential dam failures. Accurate forecast of inundation levels and the time of flood wave arrival at downstream key places is required for the development of effective emergency response plans.

1. Introduction

In Malaysia, there are almost 104 recorded dams, 81 of these dams are categorized as large dams with more than 15 meter high while the remaining 23 are small dams. Currently, earthfill dams make up about 60% of all dams, and their ownership varies [1]. We have not had any dam-related failures up to this point. The nearest dam-related incident was in 2013, when Sultan Abu Bakar Dam in Ringlet, Cameron Highlands, experienced a significant water flow from its spillway. The tragic event that occurred on October 23, 2013, in Bertam Valley, Cameron Highlands, has been viewed as a wake-up call for everyone involved, even in the absence of a dam failure. Roughly 90 houses were damaged when the Sultan Abu Bakar Dam's water level increased due to heavy rainfall. The control gate was opened to avoid damage to the dam due to the excessive amount of water. November 2017 floods in Perlis occurred due to excessive rains that damaged the Timah Tasor dam. Because the reservoir's water level had risen to 29.7 m, higher than its typical level of 29.5 m during that occurrence, an extra outflow from the dam was seen to occur. Such action was done to prevent the dam from falling, which may have caused more significant harm to the areas downstream.

Simulations of dam break events are crucial to characterizing and reducing threats due to potential dam failures [2]. In all post-event natural disasters, where most structural countermeasures have been lost, the preparation of a smoother evacuation mechanism remains the most critical prevention tool for successful evacuation planning [3]. The urgency of designing an appropriate emergency planning is important in response to the disaster. The development of effective emergency action plans requires accurate prediction of inundation levels and the time of flood wave arrival at a given location. Dam break studies are important for predicting inundation levels and flood-prone zones in the downstream area of a dam. These studies estimate the potential risk from a dam and are crucial in any assessment of the potential loss of life and property damage. Dam break studies help in ranking dams based on their potential for loss of life and property damage [4].

To perform a dam break analysis, hydraulic modelling is required, which involves routing the inflow flood through a reservoir, estimating dam breach characteristics, and downstream routing/modelling issues. The HEC-RAS (River Analysis System) software is commonly used for dam break studies. The software provides information on how to perform a dam break analysis, including the unique hydraulic modelling aspects that are required. Dam break studies are significant for predicting the potential risk from a dam, ranking dams based on their potential for loss of life and property damage, and understanding the impact of floodwater on houses. These studies involve hydraulic modelling, which is performed using software such as HEC-RAS.

2. Methodology

The research framework should be conducted to ensure the smooth running of the research process. The research framework is also important to make sure the objectives of the study achieved. The results and findings of a study depend on a complete and systematic research framework. The research framework of this study is established and described in Fig. 1.

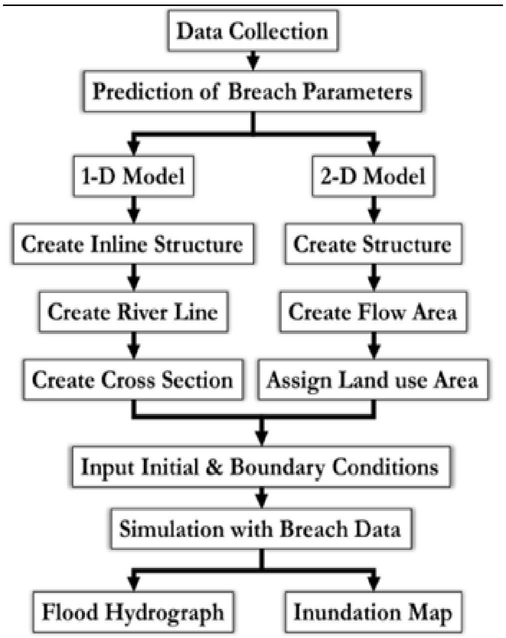

Fig. 1 *General flow diagram of dam breach modelling*

2.1 Study Area

Batu Dam, located in the district of Gombak, Selangor, Malaysia. Its construction began in 1985 and was completed in 1987. The Batu Dam catchment is in Peninsular Malaysia, approximately 20 km north of Kuala Lumpur, at 3°16'20'' N latitude and 101° 41'9'' E Longitude. The Batu Dam is around 16 km from Gombak, Selangor. It is situated upstream of the Kuala Lumpur city centre and directly downstream of the meeting.

The Batu Dam was constructed to manage sediment, supply water for industry and municipalities, and aid in preventing flooding in Kuala Lumpur. Up to a 100-year flood frequency, it offers flood storage. The construction of the dam cost RM 20 million, excluding the purchase of land. By keeping Batu Dam operational and raising the reservoir level, flooding in downstream regions has been decreased. Puncak Niaga is now drawing water out of the dam to supply industrial and residential water to different parts of Kuala Lumpur. The dam's location is displayed on the world's map in Fig. 2. An overview of Batu Dam and its constituent parts is presented in Fig. 3, and the details and attributes of the dam are listed in Table 1.

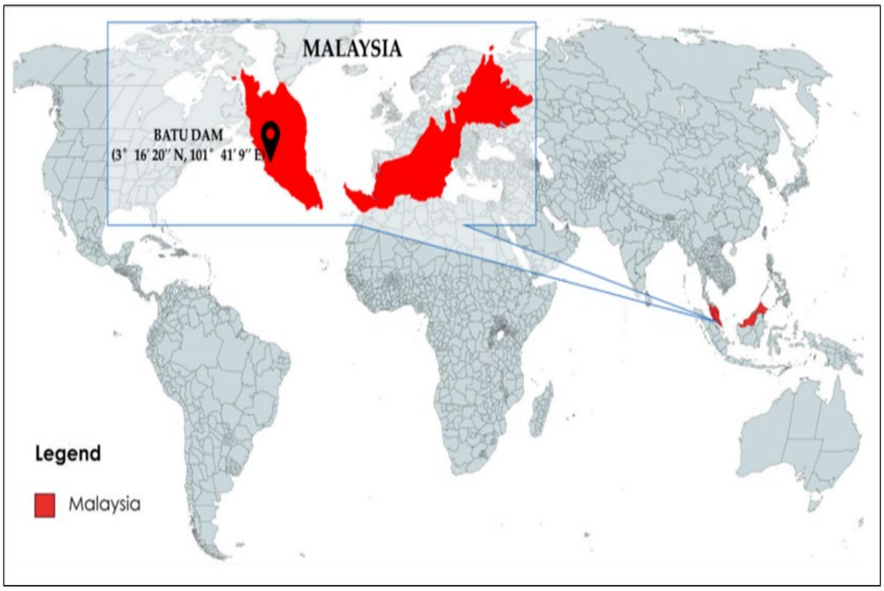

Fig. 2 *Location of Batu Dam in world map*

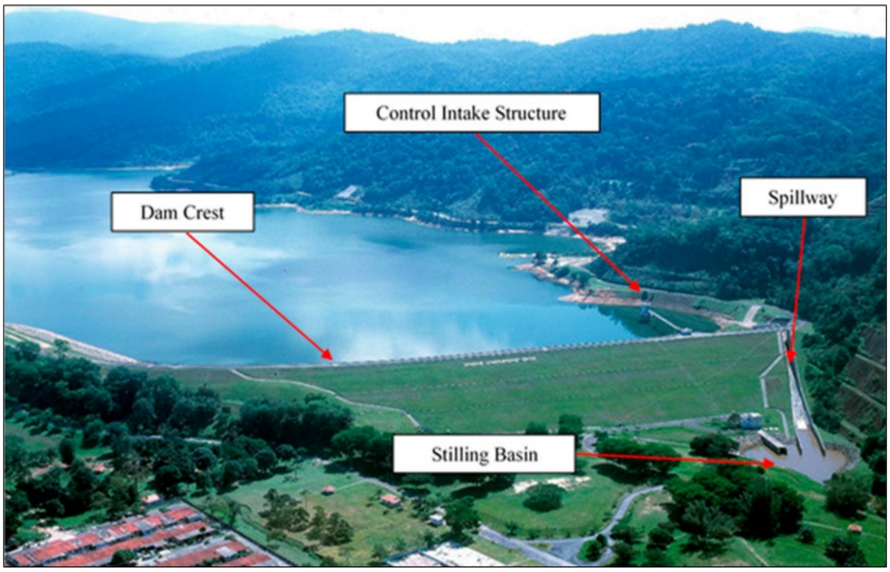

Fig. 3 *An overview of Batu Dam and its components*

Table 1 *Basic information and characteristics of Batu Dam*

Name of dam	Batu Dam
Type of dam	Earthfill
Reservoir area	2.5km^2
Height of dam	44m
Crest length	550m

Crest elevation	109mRL
Normal operation level	102.7mRL
Spillway type	Ungated side channel inlet ogee crested
Spillway crest level	104.85mRL
Use of dam	Water supply
Storage capacity at normal level	31.9mill m^3

3. Hydrological Analysis

The main purpose of the hydrology analysis is to forecast reservoir inflows and calculate the Probable Maximum Precipitation (PMP) and Probable Maximum Flood (PMF) values for Batu Dam. The reservoir, PMP, and PMF employed in the dam design will be reviewed using the appropriate technique. The availability of long-term rainfall data for rainfall stations in the research area is a basic need for PMP estimate. Rainfall plays a significant role in the hydrological cycle.

3.1 PMP by Statistical Hershfield Method

The data of yearly observed 1-hour, 3-hour, 6-hour, 12-hour, 1-day and 3-day maximum rainfall for three (3) stations in Batu Dam Catchment was analyzed to obtain estimates of PMP by the method described in the preceding sub-section. For this purpose, the values of $f\bar{x}_n$, $\bar{x}_{n-1}$, σ_n and σ_{n-1} and the coefficient of variation (CV = $\sigma_n/\bar{x}_n$) were calculated for the annual maximum rainfall series using conventional procedures. The frequency factors K_m for 1-hour, 3-hour, 6-hour, 12-hour, 1-day and 3-day durations for each station were determined by using Eq. (1).

$$K_m = \left(X_1 - \bar{x}_{n-1}\right)/\sigma_{n-1} \quad (1)$$

where $\bar{x}_n$ = Mean of annual maxima, σ_n = Standard deviation of annual maxima, K_m = Frequency factor, X_1 = Highest observed annual maximum rainfall, $\bar{x}_{n-1}$ = Mean annual maxima, excluding highest, and σ_{n-1} = Standard deviation of annual maxima, excluding highest.

4. Hec-Ras Analysis

A one-dimensional steady flow model called HEC-RAS is used to determine the water surface profile. Four primary options exist within HEC-RAS for river study: water analysis, sediment transport and riverbed modification measurement, simulation of irregular water flow, and constant flow rate at the surface of a river profile. Additionally, it can be applied to the simulation of the progression of floods in one or two dimensions.

4.1 Data Collection

Before running the HEC-RAS program, several input parameters were required for the process of hydraulic geometry of dam flow and water movement analysis. The topography of Batu Dam is illustrated and defined by using the Digital Elevation Model (DEM) in QGIS 3.28; an extension of Arc-GIS developed with the Hydrologic Engineering Centre (HEC). Digital elevation data were produced by using data from the Shuttle Radar Topography Mission (SRTM). A raster illustration of a continuous surface, usually the surface of the earth, is called a DEM. Derek Watkins provided the DEM data, which had a resolution of 1-Arc Second Global, or roughly 30 m resolution. Depending on the location selected, the SRTM data was separated by tile. Next, the raster data was projected to Kertau_UTM_Zone_48N instead of GCS_WGS_1984 as a new coordinate system. Following projection of the raster data, the data was exported and saved as TIFF (Fig. 4). After that, the TIFF file was moved and opened in HEC-RAS for analysis.

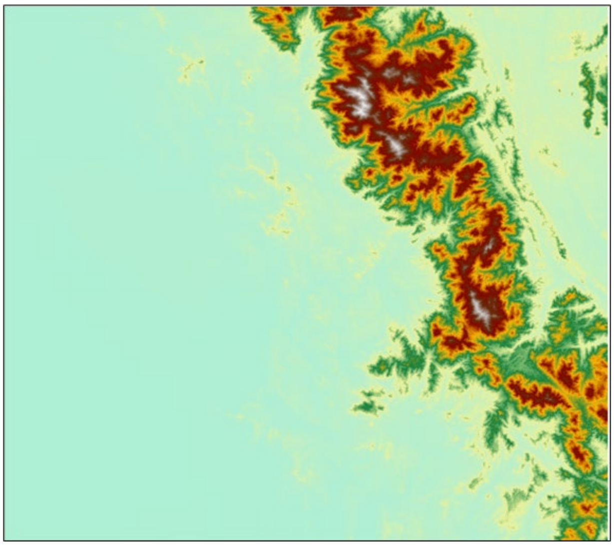

Fig. 4 *Batu Dam topography in TIFF format*

5. Results and Discussion

Three flood parameters which are depth, velocity and arrival time have been considered and combined to assess the impact and identify population at risk (PAR) in the study area. Flood depth indicates the extent of flooding, the greater the depth, the more severe the flood's impact [5]. Flood velocity is directly associated with the destructive force of the flood wave where the higher the velocity, the greater the destructive force. In general, flood velocity decreases further downstream. Flood arrival time indicates the time taken for the flood to arrive the populated area. Control measures can be taken from the time arrival to reduce the disaster impact in the study area. This result from the dam break assessment is useful to assist local agencies and emergency responders in the formulation of warning and evacuation procedures to save the communities if dam failure occurred [6]. Indeed, the findings would increase the preparedness and can be conveyed to the community to prepare them for unfortunate accidents from the dam.

5.1 Dam Break Flood Hazard Analysis

The affected area and the flood boundary were predicted using data from aerial images. Based on the most critical or worst-case scenario resulting from a dam breach event, the hydrological model by Department of Irrigation and Drainage (DID) was chosen to simulate a 50-year return period scenario. People living near the flood boundary are classified as population at risk (PAR) [7]. The flood boundary results for the chosen locations in the study area, Persiaran Jasa Utama, Kampung Nakhoda, Kampung Laksamana, and Kampung Baru Batu are displayed in Fig. 5 to Fig. 8.

Fig. 5 *Boundary of flood at Persiaran Jasa Utama*

Fig. 6 *Boundary of flood at Kampung Nakhoda*

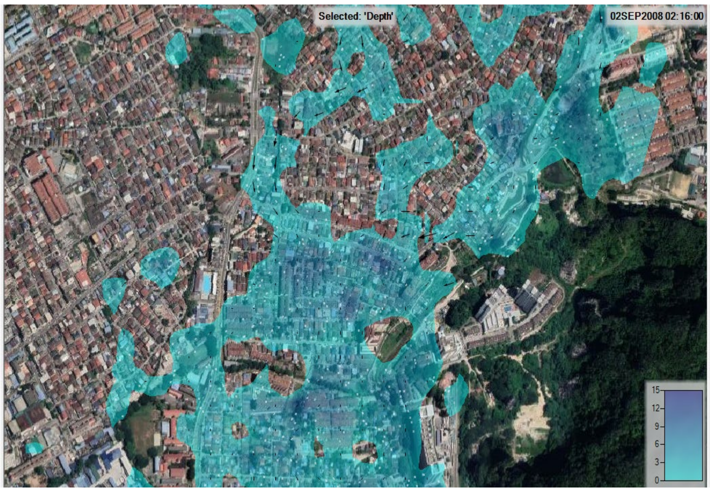

Fig. 7 *Boundary of flood at Kampung Laksamana*

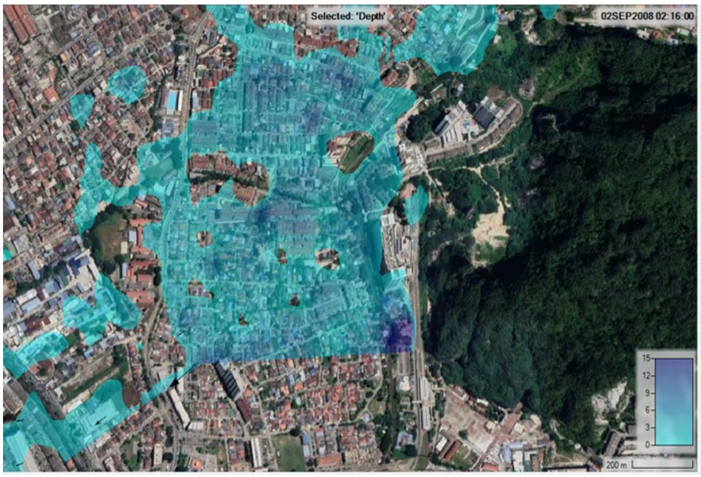

Fig. 8 *Boundary of flood at Kampung Baru Batu Caves*

A dam break flood event is predicted to occur downstream of Batu Dam based on the results of flood boundary maps. The communities downstream of the Batu Dam, namely Persiaran Jasa Utama, Kampung Nakhoda, and Kampung Baru Batu Caves, will be particularly impacted. The total area that would be submerged downstream of the Batu Dam is roughly 2.49 km^2. This region is thought to be flood-prone and highly exposed to the effects of a dam-related disastrous event. Table 2 shows the results of the study.

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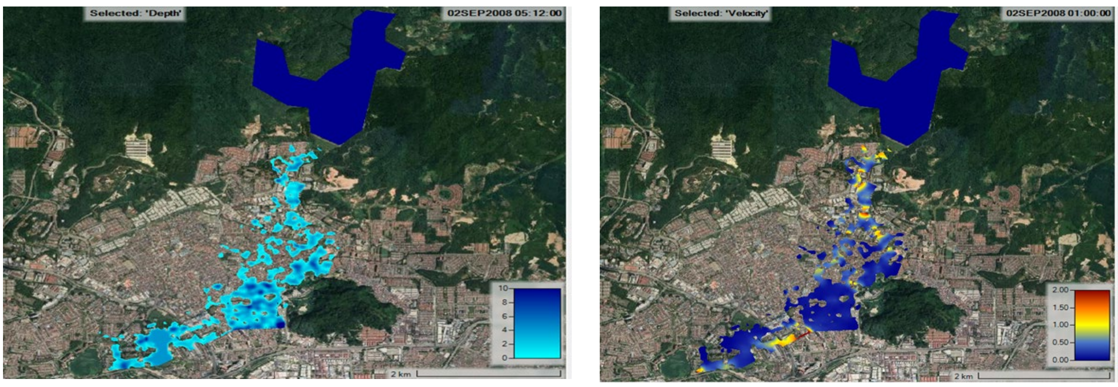
Table 2 *Affected areas during dam break*

Location	Inundated area (km^2)	Populated area (km^2) (A)	Inundated at populated area (km^2) (B)	% Inundated at populated area (B/A)
Persiaran Jasa Utama	0.24	0.16	0.13	81%
Kampung Nakhoda	0.69	0.52	0.45	87%
Kampung Laksamana	0.85	0.69	0.36	52%
Kampung Baru Batu Caves	0.71	0.58	0.52	90%
Total	2.49	1.95	1.46	78%

It was calculated that 78% of residential areas will be impacted by a dam breach disaster based on the flood boundary maps. Each of the locations in the research areas would see an impact on more than 50% of the populated area. Therefore, evacuating those who are at risk as soon as possible before the flood reaches their location is the greatest approach to reduce the risk and save lives. Thus, in order to deal with the dam breach disaster, community preparedness and quick action are essential.

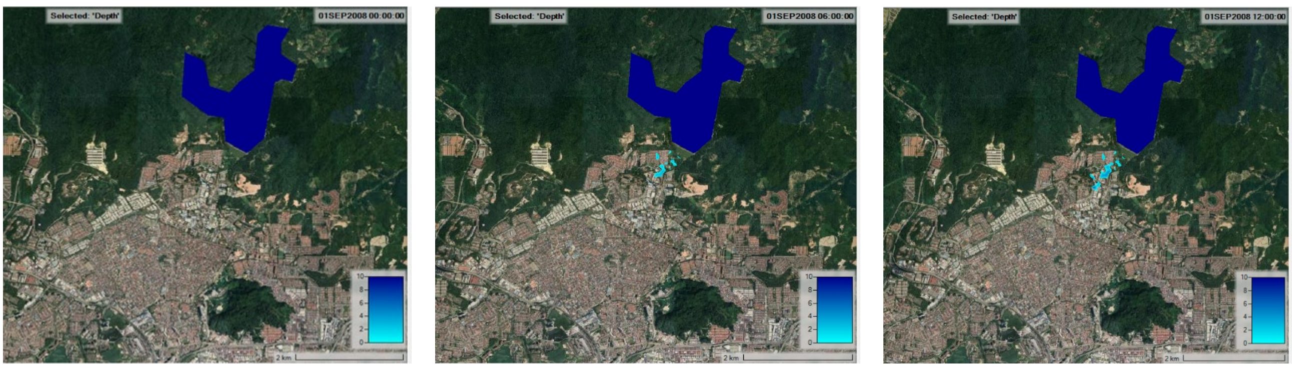
5.1 Flood Hazard Map

The flood hazard maps determine the boundary and extent of flood depth and flood velocity. Flood hazard severity is indicated by the various flood flow zones and depth with a range of colour layers. Overall detail maps on depth and velocity of flood were produced as shown in Fig. 9 while snapshot of flood arrival time was shown in Fig. 10 for every 6 hours.

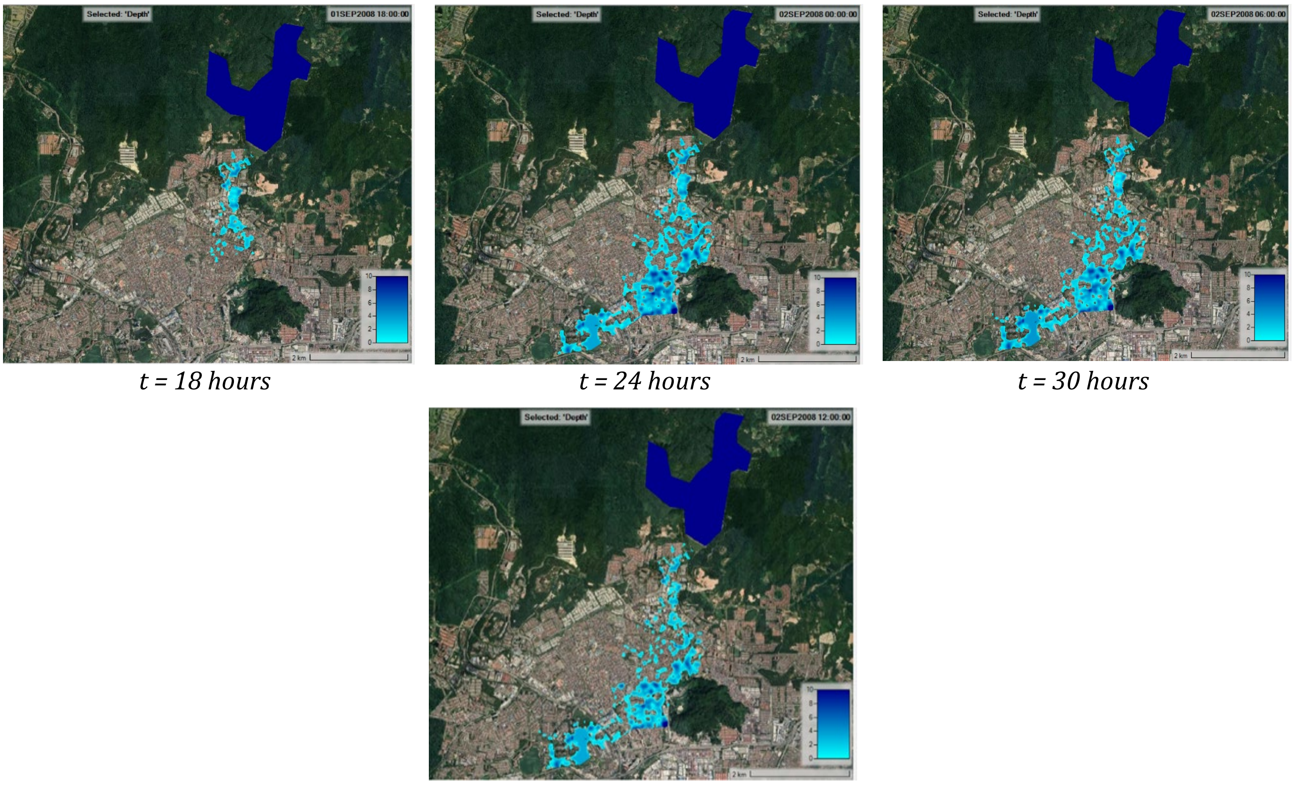


(a) **(b)**

Fig. 9 *(a) Flood water depth; and (b) flood water velocity at Batu Dam*



t = 0 hours *t = 6 hours* *t = 12 hours*



t = 18 hours *t = 24 hours* *t = 30 hours*

t = 36 hours

Fig. 10 *Flood arrival time to the downstream area for every 6 hours*

Flood arrival time, maximum flood depth and maximum velocity are extracted from the simulations to quantify flood impact assessment. Flood arrival time is defined as the time taken for the flood wave to reach a particular location in the flood plain since the dam break initiation. From the simulation, the maximum depth can reach up to 18 m with an estimated flow speed between 0.2 m/s – 3 m/s. At these depth and flow speed, people may lose strength and unable to control themselves in flood and would cause death and injury. The highest flow speed occurred along the downstream area and getting lesser to the uphill area which is Batu Caves hill. The selected floodplain locations result at study area were summarized in Table 3.

Table 3 *Affected location with different parameters under scenario of Batu Dam*

Location	Distance from the dam (km)	Flood arrival time (hour)	Maximum flood depth (m)	Flood velocity (m/s)
Persiaran Jasa Utama	0.63	15	5.07	1.60
Kampung Nakhoda	2.5	18	6.72	0.95
Kampung Laksamana	3.2	20	8.35	1.15
Kampung Baru Batu Caves	3.7	22	12.62	1.46

Based on the results mapping of flood depth and velocity induced by dam-break disaster (Table 3), several factors can affect the speed of flood flow to the downstream area depending on the specific circumstances surrounding the dam failure and the characteristics of the downstream area also the volume of water released [8]. Flood arrival time took 15 to 22 hours for flooding to arrive downstream with maximum flood depth of 5.07 m at Persiaran Jasa Utama and the highest depth of 12.62m at Kampung Baru Batu Caves with flood velocity between 1.60 m/s to 1.46 m/s.

The flood velocity can increase the depth of flood waters when the speed of velocity increases. They can pile up and create deeper water in some areas of the floodplain. This can increase the risk of drowning and make it more difficult to evacuate people and animals from affected areas. However, even the flood velocity is low, it can be dangerous especially if they contain debris or other hazards. Time taken to evacuate is very important to ensure that people's life is not threatened.

6. Conclusion

Even though the dam breach event is complicated and unpredictable, catastrophe mapping and risk assessment are critical since they may be used as primary information in building adequate prevention and mitigation strategies. This study was able to do so by utilizing empirical equations and the HEC-RAS simulation engine present an overview of sequential event in anticipating the breach formation time of Batu Dam and flood propagation along downstream locations. With the highest percentage of people at risk (PAR), Batu Dam is most likely vulnerable to a flood disaster due to the dam break. According to flood boundary maps, in the event of a dam break event, 78% of residential areas would be impacted. From the simulation, the maximum depth can reach up to 18m with an estimated flow speed between 0.2 m/s – 3 m/s. At these depth and flow speed, people may lose strength and unable to control themselves in flood and would cause death and injury. Flood arrival time took 15 to 22 hours for flooding to arrive downstream with a maximum flood depth of 5.07 m at Persiaran Jasa Utama and the highest depth of 12.62m at Kampung Baru Batu Caves with flood velocity between 1.60 m/s to 1.46 m/s. Analysis and simulation of embankment dam breach events and the resulting floods are crucial for distinguishing and mitigating dangers from potential dam failures. Accurate forecast of inundation levels and the time of flood wave arrival at downstream key places is required for the development of effective emergency response plans

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *S. I. N. S. Hashim, S. H. A. Talib, M. S. Abustan;* ***data collection:*** *S. I. N. S. Hashim, E. A. K. A. E. Mohamed, Z. Muhammad;* ***analysis and interpretation of results:*** *S. I. N. S. Hashim, S. H. A. Talib, M. S. Abustan;* ***draft manuscript preparation:*** *S. I. N. S. Hashim. All authors reviewed the results and approved the final version of the manuscript.*

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