A hydrodynamic modelling of proposed dams in reducing flood hazard in Kelantan Catchment

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Abstract. Flood is natural disaster that can cause damage and death. The flood that hit Kelantan in 2014 was the worst flood in Malaysian history. Although the disaster could not be avoided, awareness and preparedness could have helped to reduce the impact. Kuala Krai located at the downstream area in Kelantan catchment is the most affected due to the 2014 floods. The confluence of Lebir and Galas rivers into Kelantan river has led to the increase of flood magnitude to the downstream area. Therefore, Kemubu dam and Lebir dam, located along Galas river and Lebir river, respectively, have been proposed by the Kelantan authority to reduce the flood hazard. In this paper, a hydrodynamic modelling study is carried out, which is coupled of 1D and 2D model to simulate the flood event with and without the proposed dams. The model is developed using a Digital Terrain Model (DTM), which was generated from Airborne LiDAR and SRTM data sources. The hydrograph and water level for 2014 floods event were obtained and was set as an input data for boundary conditions. The modelling results of maximum velocity of 33 m/s and water depth of 19 m were used to generate flood hazard map. The result has found that the proposed dams were able to reduce the flood hazard, particularly at Kuala Krai, Kelantan.

1. Introduction

Flood is one of natural disasters that occur due to extreme weather event. Although Malaysia is less exposed to disasters like earthquakes and tornadoes, the country frequently experiences severe floods especially in the east coast of Peninsular Malaysia. Avoiding the flood catastrophe is impossible, thus one has to live with the disaster by reducing the impacts. Therefore, preparation and awareness such as the structural and non-structural approaches are essential for flood control and mitigation [8],[3]. Basically, the structural approach focuses on engineering work. The works involve either redesigning the existing infrastructures or implementing some new physical barriers to flood events intended to reduce the impact of flood hazard [5]. In contrast to structural approach, management method is applied to confront the flood disaster. Rapid advancement in satellite based technologies, spatial data analysis and modelling has opened up opportunities for researchers to develop more accurate flood risk models where floods can be managed properly and wisely [6]. Hydrodynamic modelling together with Remote Sensing and Geographic Information System (GIS) has been major tools that have enabled the mapping of different flood scenarios and the associated risks presented in timely manner [7]. The computational numerical model can also provide information such as flood extent, water depth and flood wave arrival time as well as predict the flood propagation [12]. From hydrodynamic modelling, flood mitigation planning can be constructed for preparedness in facing the flood event in future. Hence, this paper aims

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to assess the implementation of the proposed dams at the upstream area in reducing flood hazard in Kelantan using a hydrodynamic modelling approach.

In 2014, some states in east coast part of Peninsular Malaysia were hit by an unexpected and unusual flood where the increase of the flood magnitude compared to the previous flood caused greater adverse consequences to some particular states. In this event, Kelantan was the state most severely affected by the flood, which was recorded as the worst in history of the state by The National Security Council [1]. The magnitude of flood which is beyond expectation creates difficulties for the emergency response to handle this issue. Even worse, the electricity failure has limited the communication and has made the aid and relief supply to the affected area by floods became complicated. Since occurrence of the massive flood, Kelantan authorities have proposed the construction of Kemubu dam and Lebir dam along the Galas river and Lebir river, respectively. There is a need to build the dams at the Galas and Lebir rivers because the confluence of these rivers, which merge into Kelantan river, has led to great flood magnitude to the downstream area, particularly in Kuala Krai. Hence, it is crucial to assess the effectiveness of the proposed dams in reducing the flood hazard in Kuala Krai, Kelantan by simulation of 2014 flood event with and without the proposed dams by coupling a 1D and 2D model.

2. Study Area

Kelantan is one of the east coast states situated at northeast part of Peninsular Malaysia with latitude of 5° 15′ 0″ N and longitude of 102° 0′ 0″ E. With a total area of 5,830 square miles, Kelantan state comprises a population of 1,718,200. It has temperature of 21°C to 31°C and receives rainfall throughout the year. The maximum annual rainfall of Kelantan can reach 1750 mm, with most rainfall occurring during the monsoon season in November to January. It consists of ten districts which are Kota Bharu as capital city, Tumpat, Bachok, Pasir Mas, Tanah Merah, Jeli, Machang, Pasir Putih, Kuala Krai and Gua Musang. Kelantan river constitutes as a major water resource for this state. This river merges at the confluence of the Galas and Lebir rivers near Kuala Krai and transformed into broader stream with mud-colour. Then, it meanders over the coastal plain until it flows out into the South China Sea, which is about 12 km north of Kota Bharu. Meanwhile, Kuala Krai formed as a hilly land area where previously before the 20th century, the entire area was tropical rain forest. When the transportation link improved during 20th century, settlements became established along the railway routes in Kuala Krai territory where the main activities for population in this area was agriculture. The study area is the Kuala Krai district where the proposed dams are located at the upstream part of Kelantan particularly at the main tributaries Galas river and Lebir river, respectively. In this study, the floods observed at the downstream area are focused on the area after the confluence of Galas and Lebir rivers. Figure 1 shows the location of study area.

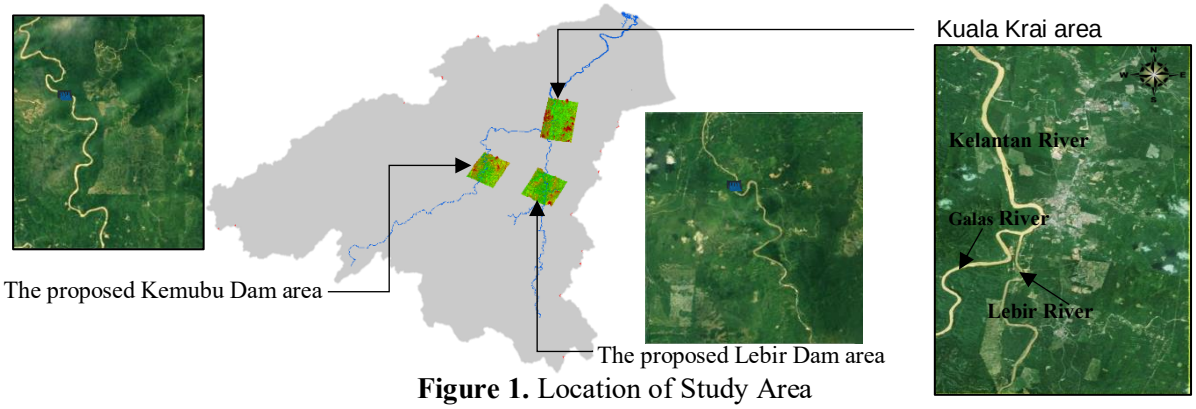


Figure 1. Location of Study Area

3. Material and Method

Information required for flood modelling are DTM, landuse data, hydrological data, cross sections and river network. The model consists of five main phases which are i) Data Acquisition; ii) Pre-processing; iii) Model Schematization; iv) Flood Simulation and v) Generation of flood hazard map.

3.1 Data Acquisition

The DTM data used in this study is LiDAR and SRTM data sources. The LiDAR data comes with 3 m spatial resolution while SRTM is 30 m spatial resolution. The DTM were combined to create new raster of study area with a new spatial resolution of 15 m. In order to produce a realistic flood simulation, the existing landuse map retrieved from Department of Agriculture (DOA) is used to estimate Manning's *n* value. Meanwhile, the hydrological data consists of discharge and water level data obtained from the Department of Irrigation and Drainage (DID). Cross sections and river networks also are required purposely for computational of 1D model. The river network is obtained from DID where it includes the river networks of whole Kelantan state.

3.2 Pre-Processing

3.2.1 Formation of the proposed dams onto DTM

The proposed Kemubu and Lebir dams are formed by raising the pixel elevation of the DTM. The specifications of the dams are based on the previous report produced by *Unit Perancang Ekonomi Negeri* [11]. The location of Lebir dam is estimated at about 40 km upstream from the confluence with Galas river, while Kemubu dam is about 18 km upstream from the Kemubu railway bridge. The proposed Kemubu and Lebir dams were designed with three outlets as a spillway. The dam crest elevation is raised at 73 m and 85 m, and spillway elevation at 63 m and 78 m for Kemubu and Lebir dams, respectively. In addition, the saddle dam proposed at about 2 km northeast of Lebir dam also has its z value of DTM raised to 85 m. The aim of the saddle dam is to prevent the floods water from escaping to downstream.

3.2.2 Manning's Surface Roughness.

In this study**,** the Manning's *n* value is obtained by converting each of the landuse classes in the map [2]. The values are adjusted suitable to the surrounding of the study area, as shown in Table 1.

Table 1. Lookup table of *n* value conversion.

Landuse	Manning's *n*
Built-up Area	0.01
Cleared Land	0.01
Rubber	0.15
Forest	0.3
Paddy	0.2
Oil Palm	0.25
Others Agriculture	0.2
Water Bodies	0.033

3.2.3 Hydrograph and Water Level for Boundary Conditions.

The discharge and water level data obtained from DID were generated hourly. For the proposed Kemubu dam, the data from "Sg. Nenggiri station at Jambatan Bertam" is selected. The data taken was estimated approximately to be as high as 2009 data flood on 20-26 December during wet season in Kuala Krai [10] due to the error data measured by this station in 2014. The sensor might be affected by the flood event as there is an error in streamflow measurement. For the proposed Lebir dam, the data on 18th to 24th December were selected from "Sg. Lebir station at Kg. Tualang". Meanwhile, for Kuala Krai simulation, the data on 17th to 31st December 2014 were selected from "Sg. Galas station at Bukit Apit Dabong" and "Sg. Lebir at Kg. Tualang". The water level was taken from "Sg. Kelantan station at the Jambatan Guillermard/Kusial".

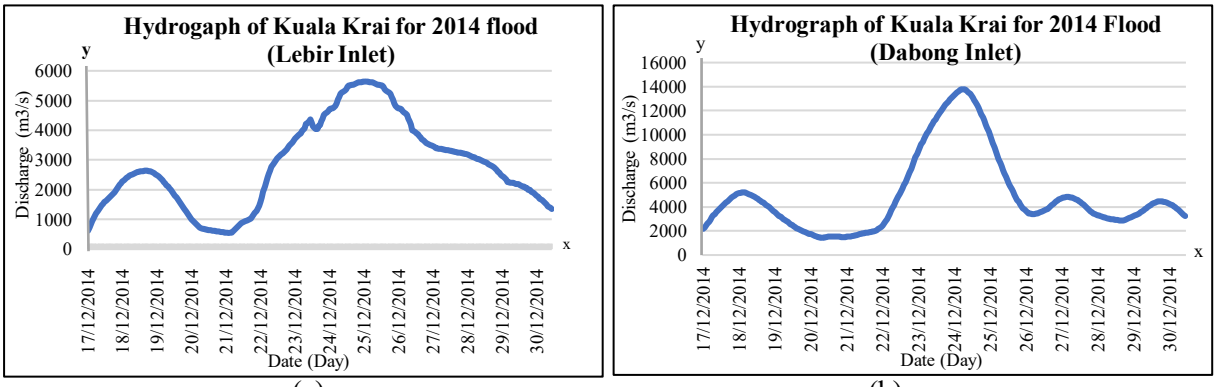
3.3 Model Schematization

3.3.1 Schematization of cross sections and river network

The river networks and cross sections are necessary to simulate the model. The river network is used as reference to digitize the reach in the model schematization. The cross sections data used in this research used recent 2014 survey data. However, the cross sections provided do not cover the whole study area for Kuala Krai, Nenggiri and Lebir rivers. For that reason, the cross sections for the rest of the study area were extracted from the DTM from LiDAR data source.

3.3.2 Defining boundary conditions

The boundary conditions have been described properly in the model setup. Boundary condition is a connecting node where the role is to define the flux relationship between the model domain area and its surrounding. The inflow boundary condition was defined by a series of discharge, *Q*, while the series of water level was used for an outflow boundary condition. Figure 2 shows the discharge hydrograph for inlet boundary conditions of the model setup.



(a) (b)

Figure 2. Discharge input data for inlet boundary conditions at; (a) Lebir river (b) Galas river

3.4 Flood Simulation

The flood simulation is focusing in Kuala Krai area considering with and without the proposed Kemubu and Lebir dams. The simulation uses a software called SOBEK hydrodynamic model developed by Delft Hydraulic in 1927. SOBEK is a powerful flood forecasting model featuring an integrated 1D and 2D model [4]. The 1D model involves each computational point corresponding to a cross section at the selected locations along river network, while the 2D model uses a finite different method for computation of the floodplain, represented in grid cells.

3.4.1 Simulation of the proposed dams

The simulation of the proposed dams is initiated after the dams have been formed onto the DTM with specification by UPEN, 1989. Figure 3(a) shows the DTM with the proposed Kemubu dam and Figure 3(b) shows the DTM with the proposed Lebir dam and a saddle dam. The simulation will also measure the discharge after the development of proposed dams.

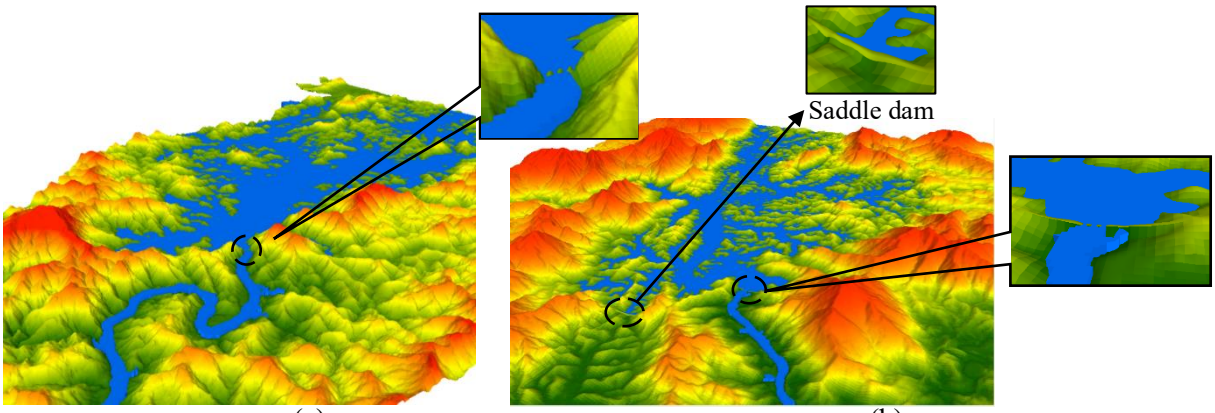


Figure 3. (a) DTM with the proposed Kemubu dam and (b) DTM with the proposed Lebir dam and a saddle dam

3.4.2 Simulation of Kuala Krai without the occurrence of proposed dams

The flood simulation of Kuala Krai without occurrence of proposed dams used two inputs from the series of discharge from Dabong and Lebir station used as inputs for inlet boundary condition. For outlet boundary condition, the series of water level from Kelantan Guillermard station is used.

3.4.3 Simulation of Kuala Krai with the occurrence of proposed dams

The flood simulation of Kuala Krai with occurrence of the proposed dams used the series of discharge measured after the overflow of flood water at the designed spillways during the simulation of the proposed dams.

3.5 Generation of Flood Hazard Map

Flood hazard map of Kuala Krai are generated by adopting the equation of Flood Hazard Rating for people defined by Department for Environment Food and Rural Affairs to determine the combinations and flood depth, flood velocity and debris factor that cause danger to people [9]. The equation is as follows,

$$HR = d \times (v + 0.5) + DF \quad (1)$$

where HR is a hazard rating of flood, d is flood depth (m), v is flood velocity (m/s) and DF indicates debris factor. The debris factor is calculated based on the indicator of debris factors for different flood depths, velocities and dominant land uses. The value of debris factor contributes to hazard are 0, 0.5 and 1, as shown in Table 2. In this study, the debris factor was set to 1 since Kuala Krai is characterized by hilly land. So, the probability that debris will lead to a hazard is high. Hazard has been categorized into four classes, which are low, moderate, significant and extreme, as shown in Table 3.

Table 2. Indicators on debris factor for different depth and velocity according to land types [9]

Depth (d)	Pasture/Arable	Woodland	Urban
0 – 0.25	0	0	0
0.25 – 0.75	0	0.5	1
d > 0.75 or v>2	0.5	1	1

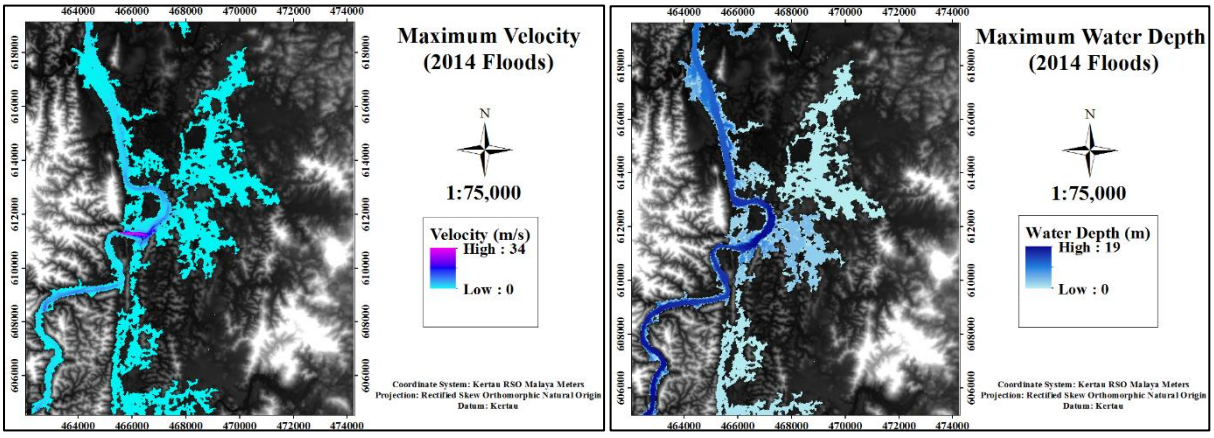
Table 3. Flood Hazard Categories [9]

Hazard Rating	Hazard Classification	Description
< 0.75	Low	Caution
0.75 – 1.25	Moderate	Dangerous for certain people such as children
1.25 – 2.5	Significant	Dangerous for most people
> 2.5	Extreme	Dangerous for all

4. Results and Discussions

4.1 Simulation Results of Kuala Krai without the proposed dams

From flood simulation of Kuala Krai without the proposed dams, two output parameters are considered, which are maximum velocity and maximum water depth. The maps of a maximum velocity and water depth are generated, as shown in Figure 4(a) and (b). The results showed the maximum velocity of 2014 flood was 34 m/s while the maximum water depth was 19 m. The flooded area of Kuala Krai was about 30 km^2.



(a) (b)

Figure 4. Kuala Krai floodplain at, a) maximum velocity, and (b) maximum water depth

4.2 Simulation Results of Kuala Krai with proposed dams

The flood simulation of Kuala Krai with proposed dams showed that no flood occurred in Kuala Krai. The discharge after the dams measured from the simulation of the proposed Kemubu and Lebir were not sufficient to trigger the flood at the downstream area. Figure 4(a) shows the flood map of Kuala Krai with the proposed dams and Figure 5 indicates the discharge hydrograph before and after the proposed Kemubu dam. It can be seen that the peak discharge after the development of Kemubu dam was decreased from 2956 m^3/s to 142 m^3/s, indicating the decrement is about 95 percent.

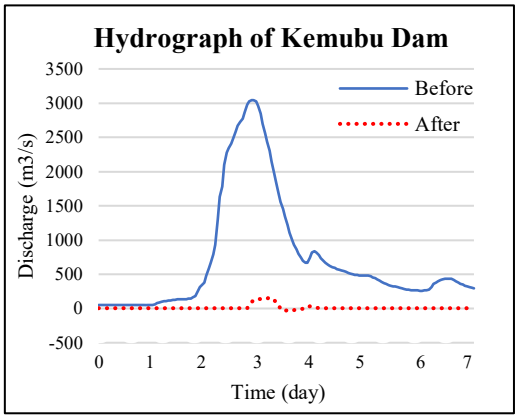
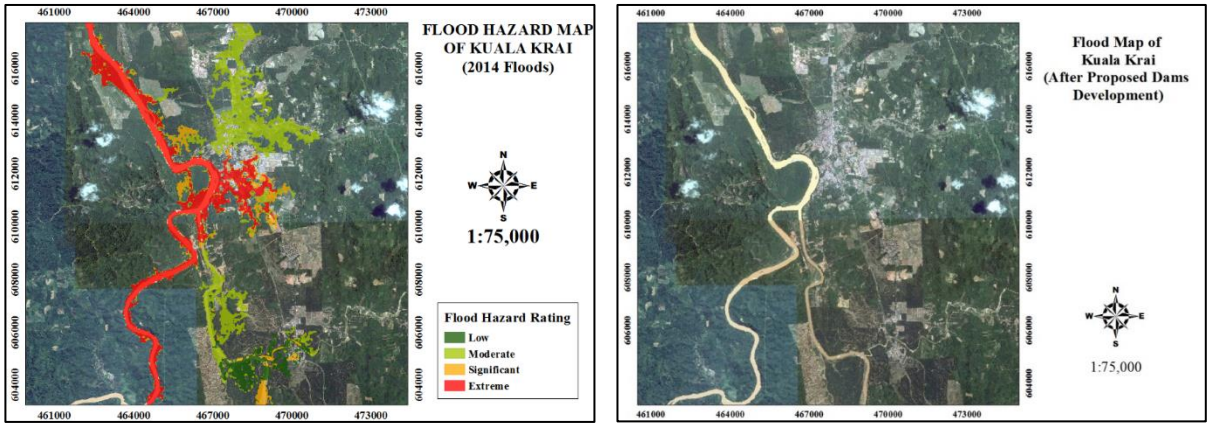


Figure 5. Discharge hydrograph before and after the development of Kemubu dam

4.3 Flood Hazard Map of Kuala Krai without the occurrence of the proposed dams

The flood hazard maps are generated using the result of maximum velocity and maximum water depth obtained. Figure 6(a) shows the hazard map of the Kuala Krai for 2014 flood without the existence of proposed dams while Figure 6(b) shows the flood map of the Kuala Krai with the existence of proposed dams. The hazard is divided into four classifications; which are low, moderate, significant and extreme.

The flooded area is measured according to hazard indicators for different flood event, as shown in Table 4. From the hazard map, the most of the flooded area were classified as extreme.



(a) (b)

Figure 6. Flood Hazard Map of Kuala Krai for 2014 flood; (a) without proposed dams, (b) with proposed dams

Table 4. Flooded area according to hazard indicators for 2014 flood event

Hazard Classification	Flooded Area (km^2)
Low	0.19
Moderate	8.64
Significant	9.82
Extreme	11.4

5. Conclusion

This study reveals that the implementation of the structural approach such as dam for flood mitigation can be assessed with the integration of hydrodynamic modelling. The results obtained from the hydrodynamic modelling at Kuala Krai with the proposed dams showed that no flood has occurred

downstream. This result however should be viewed with more aspects taken into consideration since the flood simulation has been modelled with simplification only by raising the elevation of the DTM surface model. Therefore, it can be said that the proposed dams are beneficial and capable in reducing the flood hazard in Kelantan. This study suggests that the proposed dam should be modelled with a proper plans and detailed specifications on how the dam operates, particularly for flood mitigation and hydroelectric power generation.

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