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HYDRODYNAMIC MODELLING OF A PROPOSED LEBIR AND GALAS DAM FOR FLOOD HAZARD ANALYSIS

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Abstracts: A massive flood event, which hit Kelantan in 2014, has contributed a major destruction particularly at Kuala Krai district. An alternative approach to overcome this flood episode is by constructing dams. In this study, two dams proposed at the upstream of Galas and Lebir river, near Kuala Krai. This paper aims to assess the implementation of the proposed dams which is a structural approach at the upstream area to reduce flood hazard in Kelantan using a hydrodynamic model. A coupled of 1D and 2D hydrodynamic model have been tested to simulate the occurrence of flood events in Kelantan due to the proposed dams. The Digital Terrain Model (DTM) has been generated by combining the data sources; i.e. from Airborne LiDAR and SRTM. The design of proposed dams were defined based on 50 years flood characteristics proposed by UPEN and simulated into the DTM with different magnitudes of flood. The flow hydrograph and water level for 25, 100 and 200-year return period are generated as input data for initial and boundary conditions. River cross-sections and hydrodynamic roughness value of Kelantan catchment area are also used in the model. The flood that has been observed is focused on Kuala Krai area before and after the construction of the proposed dams. The results of maximum velocity and water depth from the hydrodynamic modelling results are then generated to produce flood impulse and flood hazard maps. The results obtained from the preliminary study of the hydrodynamic modelling at Kuala Krai after the development of the proposed dams showed that no flood occurred at the downstream based on the streamflow input consideration.

Keywords: *Structural approach, flood event, hydrodynamic modelling, proposed dams, flood hazard map*

1.0 Introduction

Since Malaysia is a flood prone country especially to the east coast states, avoiding the flood catastrophe is impossible. For that reasons, one has to live with the disaster by reducing the impact of the flood event. In year 2014, some states in east coast part of Peninsular Malaysia have been hit by an unexpected and unusual flood where the increase of the flood magnitude compared to the previous flood lead to greater impact of flood consequences. In this event, Kelantan was the most severe state suffered by flood and it was recorded as the worst in history of the state by The National Security Council (Azlee, 2015). The magnitude of flood, which is beyond expectation give difficulties for the emergency response to handle this issue. Even worse, the electricity failure has limited the communication hence complicated the aid and relief supply to the flooded area. This massive flood occurred in Kelantan causes the Kemubu and Lebir dams to be proposed at the main tributaries, Galas and Lebir rivers respectively by Department of Irrigation and Drainage (DID), which is located at the upstream area of Kelantan state. The implementation of the proposed dams however is the structural approach for flood control and relief. Thus, it requires the support of non-structural approach such as hydrodynamic modelling to assess the feasibility of this structural approach in reducing the flood hazard.

Reducing the flood hazard can be accomplished by two approaches, which are structural and non-structural (Rahman, 2006; DID, 2012). The structural approach is conventional way focuses on the engineering works such as construction of levee, dam or river improvement in order to mitigate the flood event. Recently, the flood mitigation in Malaysia has been deviated from conventional measures where it involve a highly cost and concern more on combining the structural and non-structural measures (Ghani *et al.*, 2012). There are numerous hydrodynamic models such as HEC-RAS, SOBEK, MIKE 21, TUFLOW 2D and others have been developed to model the flood event. They can be in 1D, 2D, 3D and the integration of 1D and 2D. The results from simulating the flood events can help one to have some good ideas as well as better understanding on flood behavior which contributes to efficient flood management and mitigation processes (Salami *et al.*, 2014). This paper aims to assess the implementation of the proposed dams, which is the structural approach at the upstream area in reducing flood hazard in Kelantan using hydrodynamic modelling approach. Therefore, the proposed Kemubu and Lebir dams have been defined onto DTM and then simulated at Galas and Lebir rivers, respectively. Then, the flood will be observed at Kuala Krai which is the downstream area of Kelantan before and after the development of the proposed dams. The flood events have been tested using different flood magnitudes of 25, 100 and 200-years return period.

2.0 Study Area

Kelantan is a part 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. The total area of Kelantan is 5,830 square miles has comprised the population of 1,718,200. This state consists of several districts namely as Kota Bharu which is the capital city, Tumpat, Bachok, Pasir Mas, Tanah Merah, Machang, Pasir Putih, Kuala Krai and Gua Musang. There are six major sub-basins in Kelantan River basin namely Galas, Nenggiri, Pergau, Guillemard Bridge, Kuala Krai and Lebir. Kelantan River Basin has a tropical climate. It has temperature of 21 to 31 °C and receives rainfall throughout the year. Approximately, the maximum annual rainfall of Kelantan can reach 1750 mm during the monsoon season in November to January. Recent flood in 2014 triggered by monsoon rain has described as the most severe flood occurred to this state. Figure1 shows the location of study area. In particular, this study focuses on the Kuala Krai district where at the upstream part which is the location of Kemubu dam and Lebir dam have been proposed at the Galas and Lebir rivers, respectively. The dams have been located approximately near to the location suggested before in previous report by UPEN, (1989). Then, the flood will be observed at the downstream part focuses on area around the confluence of the two major Galas and Lebir rivers and northwards.

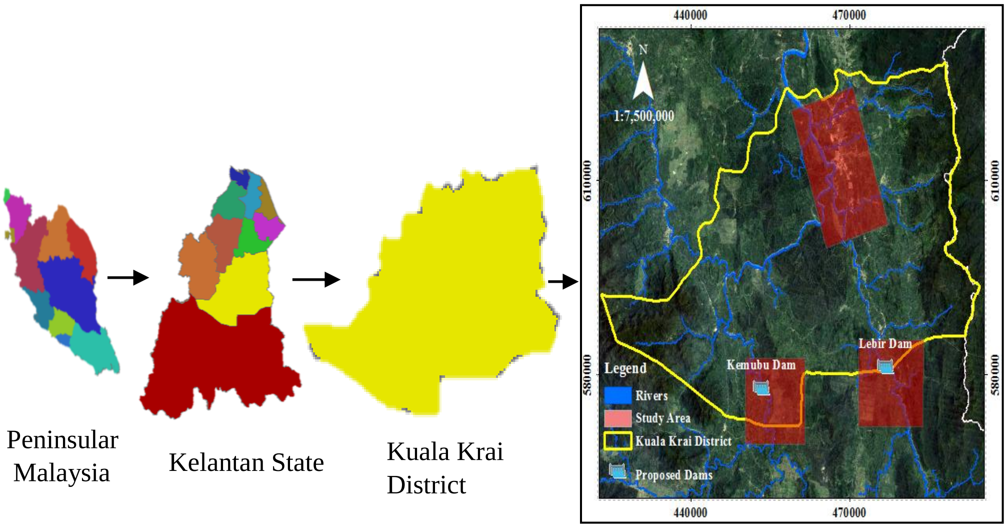


Figure 1: Area of Study

3.0 Materials and Methods

3.1 Materials

A hydrodynamic modelling requires several data such as DTM, land use data, hydrological data, cross section and river network data. The high-resolution DTM is generated from Airborne LiDAR data by using the Optech ALTM 3033 airborne LiDAR system in 2008 with spatial resolution of 3 m. The airborne LiDAR data was acquired mainly along the main river corridor in Kelantan. The STRM data have been used to add up the area, which not covered the study area. The DTM were combined into single and resampled to 15 m of spatial resolution to cope with the SOBEK's hydrodynamic model limitation. Furthermore, the land use data of year 2010 obtained from Ministry of Agricultures used to generate the manning's *n* value. The hydrological data used in this study were water level and discharge data obtained from DID. Moreover, cross section data used were a recent data surveyed by consultant in year 2016. However, the cross sections provided are not covered the whole study area for Kuala Krai, Nenggiri and Lebir rivers. For that reason, the cross section for the rest study area was extracted from the DTM of Airborne LiDAR data source. River network has been obtained from DID where it includes the river networks of whole Kelantan state. The data is in shape file format where the coordinate system is in Rectified Skew Orthomorphic (RSO). The river network used as reference to digitize the reach in model schematization. All these data are crucial to be used for model schematization.

3.2 Flood Frequency Analysis

To identify the flood flow for different return period, the Gumbel distribution was used by selecting annual maximum of discharge and water level of 16 years for Nenggiri station (1998 - 2013), 39 years for Lebir station (1976 - 2014) and 33 years for Dabong station (1977 – 2010) while for Kelantan Guillermard station, only the gauge level was used by selecting peak for 53 years (1961 – 2014). In Gumbel distribution, flood is defined as the largest of the daily flows and the annual series of flood flows constitute a series of largest values of flows. In hydrologic and meteorological studies, Gumbel distribution have been widely used probability analysis for extreme values in predict the flood flows (Jeb *et al.*, 2008; Mujere, 2011). The return period in this study are calculated in EasyFit 5.6 software to estimate the parameter by using Method of Moment. Then, Microsoft Excel software is used to calculate the quantile estimates for different return period.

3.3 Manning's n Roughness Coefficient

A manning's roughness coefficient, *n* is essential for hydrodynamic modelling where it uses to describe the water flow over the ground. It has been described as the sum of the force acting against the motion of the fluid, which is consequently limiting the velocity and exerting control over flow depth and discharge. Therefore, the manning's *n* is indirectly to the flow velocity equation as follow (Hossain *et al.*, 2009).

$$v = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}} \quad (1)$$

Where v is the flow velocity, R is the hydraulic radius, S is Channel Slope and *n* indicated the manning's roughness coefficient. The roughness coefficient value was estimated from the land use/cover map with the corresponding value shown in Table 1 have been adopted to the surrounding of the study area. The friction is higher by the increase of *n* value.

Table 1: The manning's *n* roughness coefficient value estimated from land use/cover map

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

3.4 1D and 2D Hydrodynamic Modelling

In this study, SOBEK hydrodynamic model developed by Delft Hydraulic in 1927 have been used to simulate the flood events. SOBEK is a powerful model for flood forecasting and uses an integration of 1D2D. The combination of both 1D and 2D codes instead of using 2D codes alone can gives a good representation of the channel conveyance processes, thus require in modelling the flood event (Popescu *et al.*, 2010). From combining the 1D and 2D model, it allows modelers to closely model the real situation of flood event where 1D model is simulating the flow in channel or in river with extensively detailed calculation. On the other hand, the 2D model simulates the overland flow, which incorporates detailed information on terrain (Usamah, 2005).

3.5 Defining the Boundary Condition for Hydrodynamic Modelling

In hydrodynamic modelling, it is vital to properly describe the boundary conditions. The flux relationship between the model domains area and its surrounding area has been defined by boundary condition which plays a role as connecting node. The boundary conditions can be represented as the series of discharge or series of water level and need to be defined either at lower and upper boundary of the model domain area. A misleading water balance of the system will be generated if the boundary condition is wrongly defined. This lead to the serious propagation errors throughout the simulation thus contribute to ambiguous (Ruji, 2007). In this study the upper boundary condition is defined as the series of discharge while the lower boundary is the series of water level. Figure 2 shows the boundary that has been setup for flood simulation in Kuala Krai.

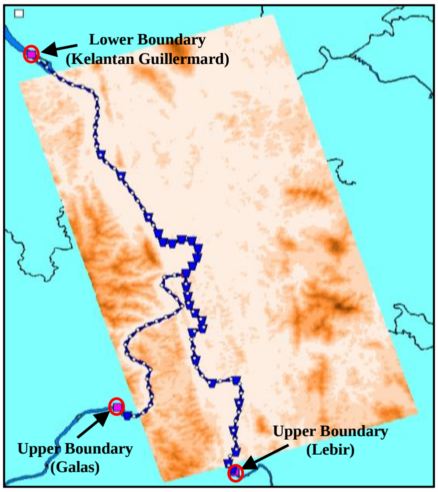


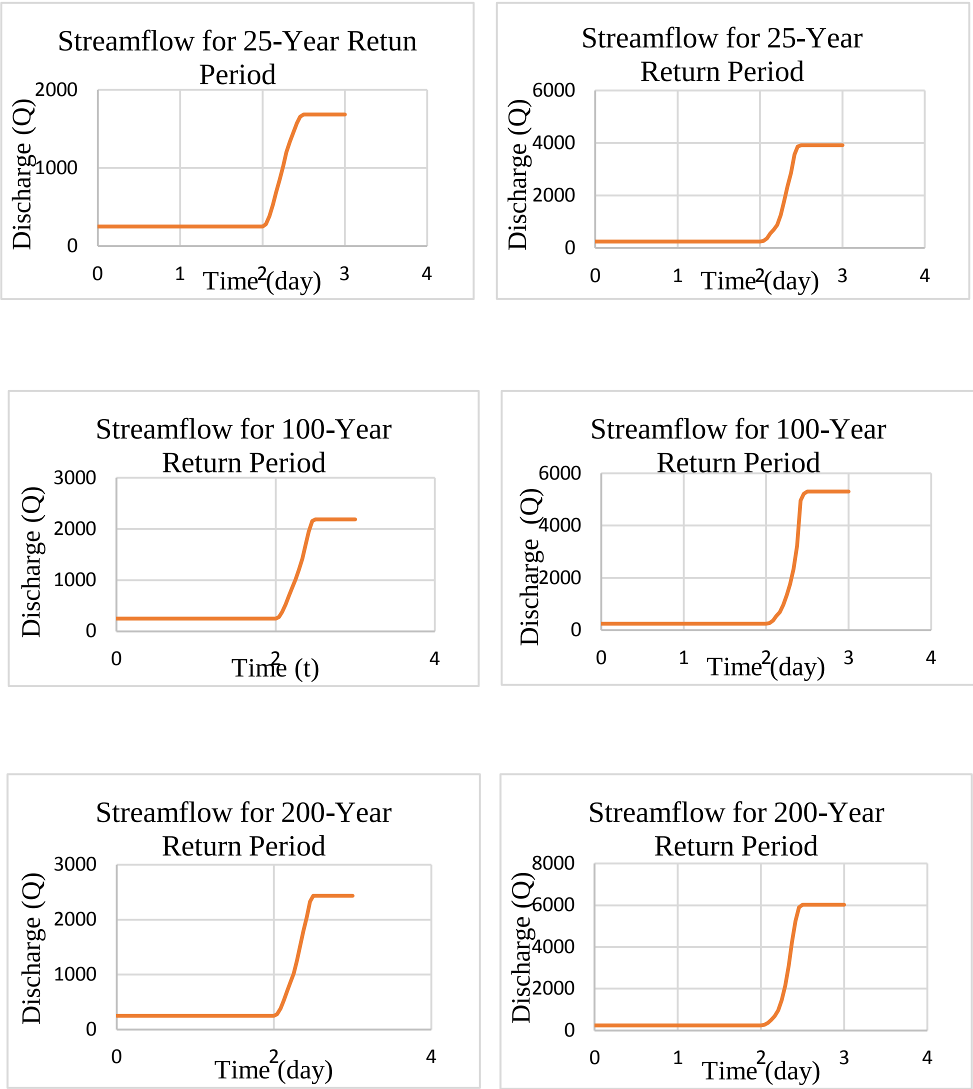
Figure 2: The boundary conditions setup for flood simulation of Kuala Krai

3.6 Streamflow Input Data for Flood Simulation of the Proposed Dams

The input of stream flow for 25, 100 and 200-years return period was generated as shown in Figure 3. The graphs are designed with a simplification of the dam operations whereas the discharge are designed as constant for first 2 days to represent the real situation process of filling the reservoir with water. The graphs showed that the stream flow starts to rise to the peak of return period as the high magnitude occurs during the flood event. The peak value of Kemubu dam for 25, 100 and 200-years return period were 1686 m^3/s, 2186 m^3/s and 2434 m^3/s, respectively. Meanwhile, for Lebir dam, the peak value were 3915 m^3/s, 5300 m^3/s and 6021m^3/s, respectively for 25, 100 and 200-years return period.

3.7 Flood Simulation of the Proposed Dams

To simulate the flood event for the proposed dams, the elevation of each dam has been defined regarding to the 50 years flood characteristics proposed by UPEN (1989), Kelantan. Table2 shows the characteristics of the proposed dams.



(a) (b)

Figure 3:Streamflow input data for flood simulation of the proposed
(a) Kemubu dam (Q=250 m^3/s), (b) Lebir dam (Q=240 m^3/s)

Table 2 : The characteristics of the proposed Kemubu and Lebir dams (Sources : UPEN,1989)

Characteristic	Kemubu dam	Lebir dam
Dam Crest Elevation (m)	73.4	84.9
Surcharge Water Level (SWL) for 50-year flood (m)	63.1	78
Normal High Water Level (NHWL) (m)	55.0	70
Dam crest width (m)	8	30
Dam height (m)	50	70
Flood control volume (m^3)	307,000000	860,000000
Embarkment volume (m^3)	150,000	4,900,000
Type of dam	Concrete gravity	Rock fill

The DTM has been modified by raised the elevation value according to the value of Dam Crest Elevation and Surcharge Water Level of Lebir and Kemubu dams respectively as shown in table above. The dams have been located approximately based on previous report by UPEN (1989), where the Lebir dam is at about 40 km upstream from the confluence with Galas river while Kemubu dam is located about 18 km upstream from the Kemubu railway bridge. There are three outlets been developed as a spillway for Kemubu and Lebir dams, respectively. The outlet purpose as one of the dam component is to transmit the flood water from reservoir in order to avoid damaging the dam structure(Chow, 1959). In addition, a saddle dam has been constructed at about 2 km northeast of the Lebir dam site to prevent the floods water from escape to downstream. All the process to define the proposed dams onto DTM was done in GIS commercial software by ESRI, ArcGIS 10.1.2. Figure 4 (a) shows the DTM with the proposed Kemubu dam onto it and (b) shows the DTM with the proposed Lebir dam and saddle dam onto it.

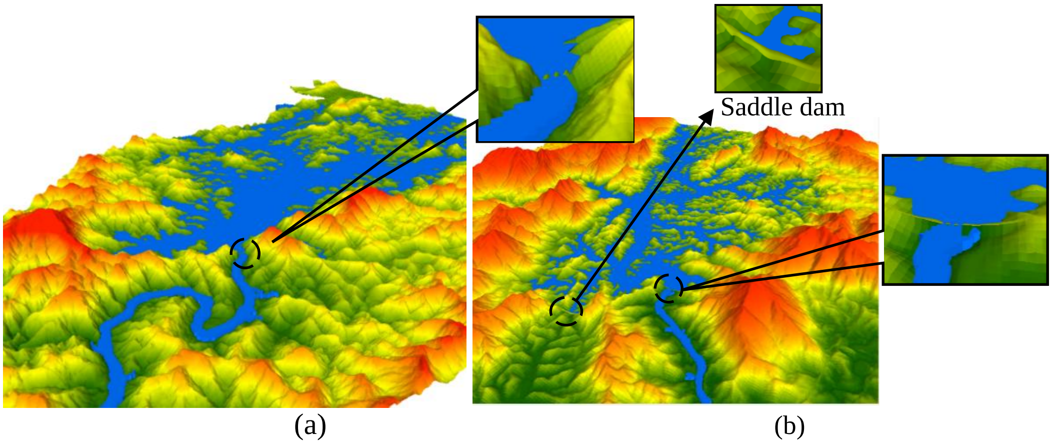


Figure 4: (a)DTM with the proposed Kemubu dam and (b) DTM with the proposed Lebir dam and saddle dam

3.8 *Flood Simulation of Kuala Krai Before the Proposed Dams Development*

For flood simulation before proposed dam of Kuala Krai, the discharges from Dabong and Lebir station was used as input data for upper boundary condition. Meanwhile, for lower boundary condition, the water level from Kelantan Guillermard station has been considered.

3.9 *Flood Simulation of Kuala Krai After the Proposed Dams Development*

The flood simulation of Kuala Krai after the proposed dams' development is initiated after the simulation of the proposed Kemubu and Lebir dams are done. This is because the discharge measured after the overflow of floods water at the designed spillways during the simulation of the proposed dams was used for boundary condition in this simulation. The measurement stations are placed after Kemubu and Lebir dams, respectively during model schematization for simulation of the proposed dams in order to record the discharge of the overflow water.

3.10 Generation of Flood Hazard Map

Flood hazard map of Kuala Krai for different returns period are generated by adopted the equation of flood hazard Rating for people defined by DEFRA to determine the combinations and flood depth, flood velocity and debris factor that cause danger to people (Ramsbottom *et al*., 2006). The equation is as follows:

$$HR = d \times (v + 0.5) + DF \quad (2)$$

Where, HR is hazard rating of flood, d is flood depth (m), v is flood velocity (m/s); and DF is debris factor (calculated using Table 3). Based on the indicators from Table 3, the debris factor are in range of 0, 0.5 and 1. In this study, the debris factor was set to 1 since Kuala Kraiis characterized by hilly land. So, the probability of debris will lead to a hazard is high. The hazard has been categorized into four classes, which are low, moderate, significant and extreme, as shown in Table 4.

Table 3: Indicators on debris factor for different depth and velocity according to land types (Sources: Ramsbottom*et al*., 2006)

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

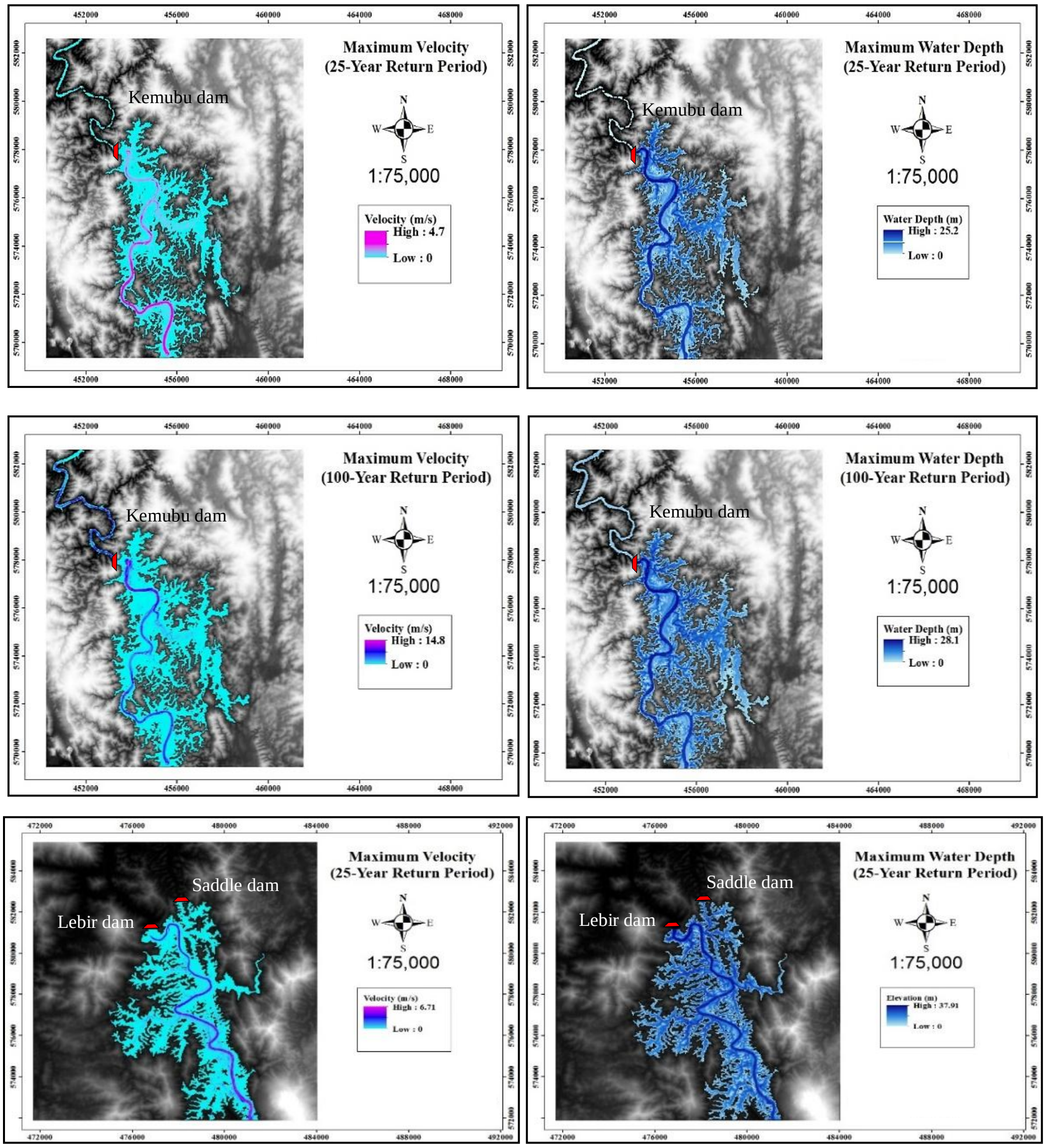
Table 4: Flood Hazard Categories (Sources: Ramsbottom *et al*., 2006)

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

4.0 Results and Discussion

4.1 Flood Simulation of the Proposed Kemubu Dam

From flood simulation for Kemubu dam, which is situated at Galas river, there are two output parameters considered, which are maximum velocity and maximum water depth. The maps of maximum velocity and maximum water depth for each flood event; 25, 100 200-years return period are generated as shown in Figure 5(a) and (b). It revealed that there has been gradual increased in magnitude of velocity and water depth as the return period of flood event are increased. The maximum velocity for 25, 100 and 200-years return period were 4.7 m/s, 14.8 m/s and 16.6 m/s, respectively. Meanwhile, the maximum water depth were 25.2 m, 28.1 m and 28.93 m, respectively. Based on the maps produced, again, it showed that the flood occurred mainly affected the upstream area before Kemubu dam while there are no flood occurred at the downstream after the dam.



(a) (b)

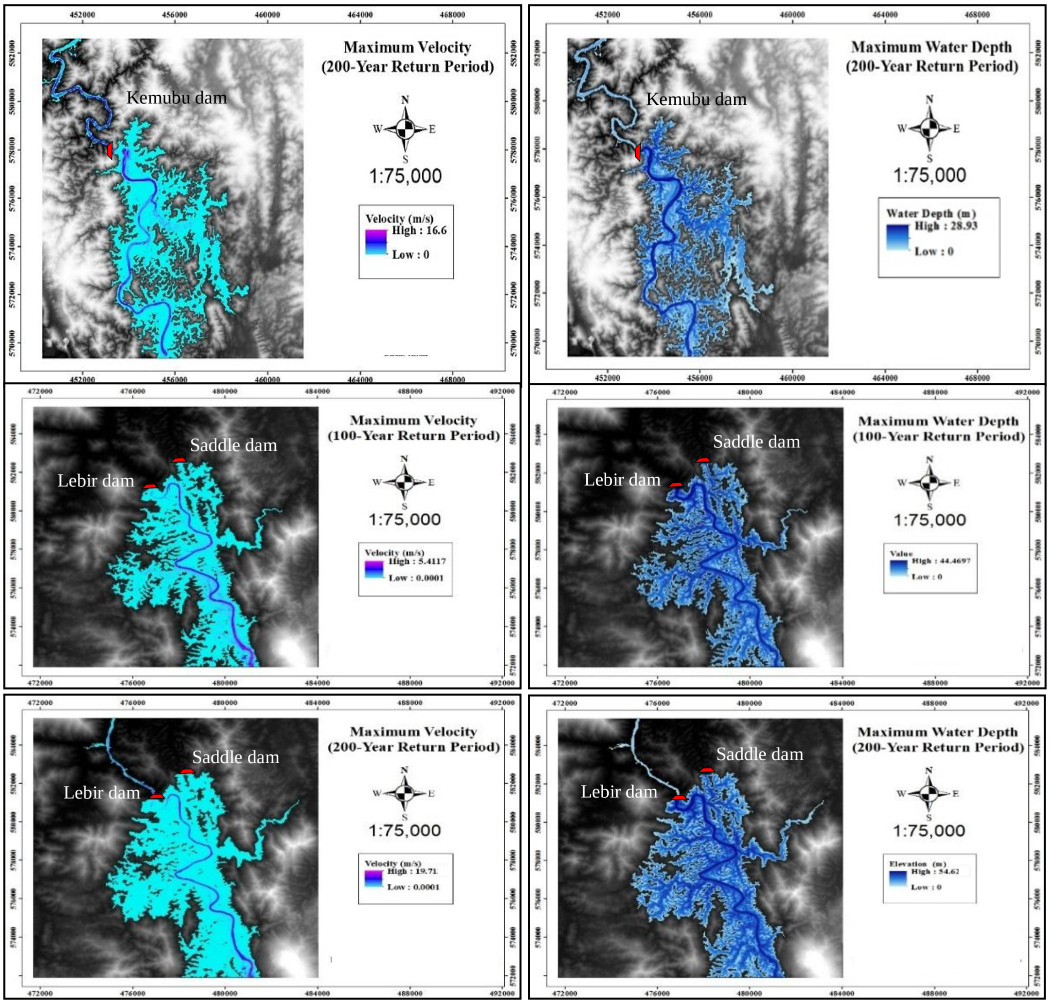
Figure 5: (a) : Maximum Velocity of Kemubu dam for 25, 100, 200-years return period (b) Maximum Water Depth of Kemubu dam for 25, 100, 200-years return period

4.2 Flood Simulation of the Proposed Lebir Dam

The maps of maximum velocity and maximum water depth from simulation of flood for Lebir dam situated at Lebir river for each flood event; 25, 100, 200-years return period and real event are generated as shown in Figure 6 (a) and (b). It revealed that the maximum velocity for 25-years return period was slightly higher than the maximum velocity for 100-years return period, 6.71 m/s and 5.41 m/s and has increased for 200-years return period to 19.71 m/s. The maximum water depth were 37.91 m, 44.46 m and 54.62 m for 25, 100 and 200-years return period, respectively. It can be said that the magnitude of maximum water depth increases as the return period of flood event increased. The results indicated that the flood occurred mainly affected the upstream area before Lebir and saddle dams while there are no flood occurred at the downstream after the dams.

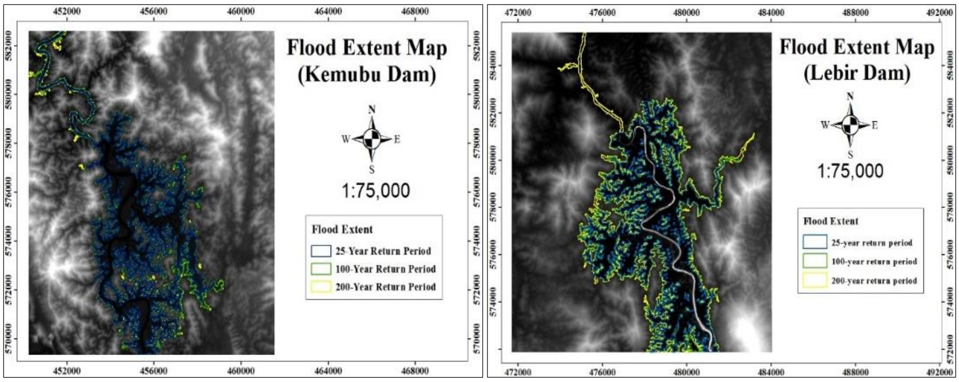
4.3 Flood Extent for Kemubu and Lebir Dams

From hydrodynamic modelling, the results obtained are used to generate the flood extent map of Kemubu and Lebir dams respectively, as shown in Figure 7 (a) and (b).The flood extents are greater by the increment of return period. The flooded areas for each event are measured for Kemubu and Lebir dams and the results are shown in Table 5.



(a) (b)

Figure 6: (a): Maximum Velocity of Lebir dam for 25, 100, 200-years return period
(b) Maximum Water Depth of Lebir dam for 25, 100, 200-years return period



(a) (b)

Figure 7: (a) Flood Extent of Kemubu Dam (b) Flood Extent of Lebir Dam

Table 5: Flooded area of Kemubu and Lebir Dams

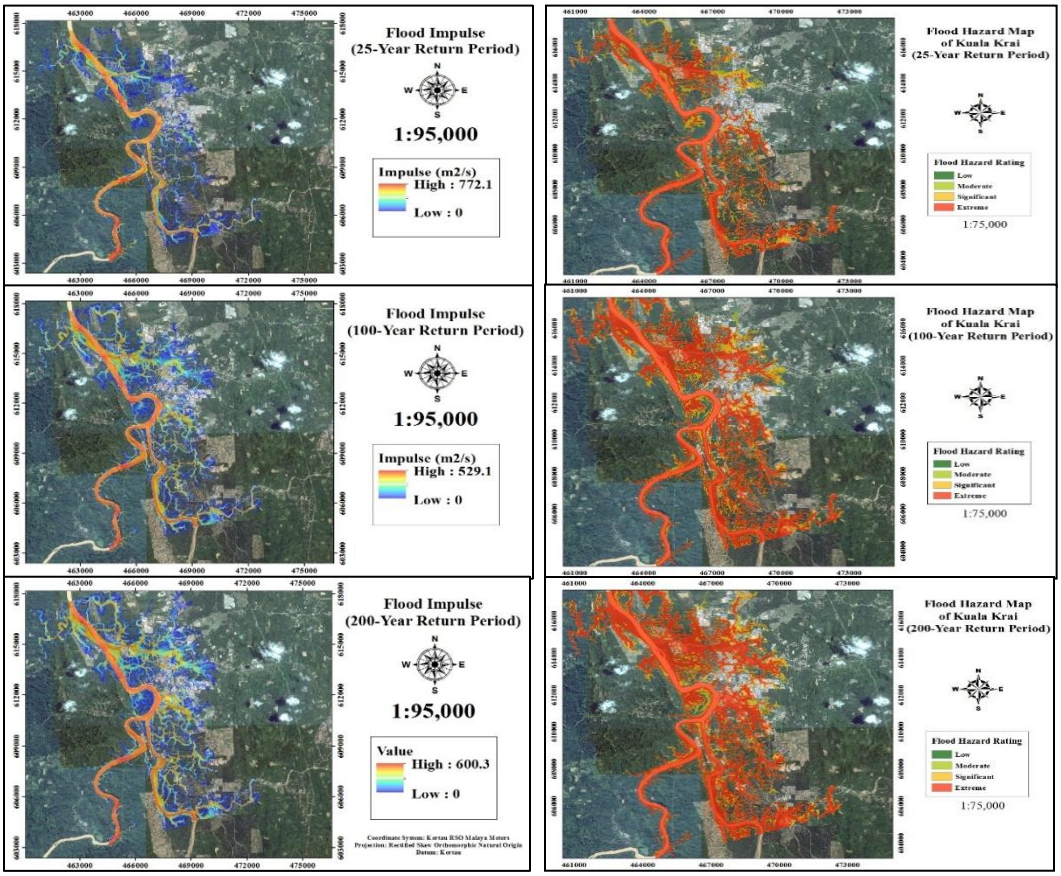
Flood Magnitude	Flooded Area (km^2)	
	Kemubu Dam	Lebir Dam
25-Year Return Period	18.97	23.61
100-Year Return Period	22.12	27.85
200- Year Return Period	22.69	33.87

The analysis of flooded area showed the Kemubu dam is, about 14percent of area increased to be flooded for 100 years return period while 2.5 percent of area flooded increased for 200 years return period. Lebir dam experienced as much as 15percent increased of flooded area for 100 years return period. For 200 years return period, the increment of flooded area is about 17 percent. It can be said that, Lebir dam has experienced a slightly greater increment than Kemubu dam by the increment of return period.

4.4 Flood Scenario of Kuala Krai Before Dams Development

Figure 8 (a) shows the maps of flood impulse of Kuala Krai for each flood event; 25, 100, 200-year return period. The flood impulse also known as flood intensity is the product of water depth and flow velocity. The maximum flood impulse for 25, 100 and 200-years return period was 772.1 m^2/s, 529.1 m^2/s and 600.3 m^2/s, respectively. Based on flood impulse maps that have been generated, the high impulse basically focused along the river. The generated flood hazard map for 25, 100 and 200-years return period in Figure 8(b) shows the hazard classification of flooded area in Kuala Krai. There are four indicators of hazard, which are low, moderate, significant and extreme. The flooded area is measured according to hazard indicators for different flood event, as shown in

Table6. From the hazard map, the most of the flooded area were classified as an extreme flood.



(a) (b)

Figure 8: (a) Flood Impulse of Kuala Krai for 25, 100, 200-years return period (b) Flood Hazard Map of Kuala Krai for 25,100 and 200-years return period

Table 6: Flooded area according to hazard indicators for different flood event

Flood Event	Flooded Area (km^2)			
	Low	Moderate	Significant	Extreme
25-year return period	0.06	1.76	6.85	19.14
100-year return period	0.07	1.95	8.38	29.18
200-year return period	0.07	1.91	8.57	33.99

4.5 Flood Scenario of Kuala Krai After Dams Development

From the flood simulation of Kuala Krai after the proposed dams have been developed, there are no flood will occur for 25, 100 and 200 years return period. The flood water discharge measured after the overflow through the outlet of Kemubu and Lebir dams have been decreased. The maximum discharge measured after Kemubu dam is 4.27 m^3/s, 136.73 m^3/s and 138.19 m^3/s, respectively for 25, 100 and 200-years return period. Meanwhile, the maximum discharge of 31.47 m^3/s after Lebir dam is measured for 200-years return period since there is no flood overflow through the outlets for 25 and 100-years return period. Thus, the low flood water discharge used as input of upper boundary condition for flood simulation were not sufficient to trigger the flood at the downstream area.

5.0 Conclusions

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 preliminary study of the hydrodynamic modelling at Kuala Krai after the development of the proposed dams showed that no flood occurred at the downstream based on the streamflow input consideration. This result however should be viewed with more aspects taken into considerations since the flood simulation has been modelled with simplification just by raised 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. So, this study suggests that the proposed dam should also be modelled with a proper plans and detailed specifications of how the dam operates especially for flood mitigation and hydroelectric power generation.

6.0 Acknowledgements

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