ASSESSMENT OF PROPOSED DAMS IN REDUCING FLOOD HAZARD IN KELANTAN RIVER BASIN USING HYDRODYNAMIC MODEL AND GEOSPATIAL TECHNIQUES

SYAZA FAIQAH BINTI MARUTI @ EZANI

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Master of Philosophy

Faculty of Built Environment and Surveying
Universiti Teknologi Malaysia

SEPTEMBER 2019

DEDICATION

With special dedication to my beloved parents.

"*Abah* will always be my hero and *Mama* will forever remain my life's biggest inspiration."

(You will always in my thoughts and my prayers, *Ma- Al-Fatihah*)

ACKNOWLEDGEMENT

All praise and glory be to Almighty Allah SWT on whom ultimately we depend for everything and only through the conscious of Allah SWT, we would achieve successful life in this world and hereafter. With His mercy, blessing, sustenance and guidance, I succeed to complete this thesis. Peace is unto Prophet Muhammad SAW the seal of all prophets. My gratitude goes to my supervisor, Dr. Shahabuddin Bin Amerudin and co-supervisor, Mr. Wan Hazli Bin Wan Kadir for their supervision in contributing ideas, assistance and suggestions throughout this Master Philosophy's journey.

Not forgotten, my special thanks are extended to the Department of Irrigation and Drainage, Malaysia for providing various data sets for this research. I also thank and acknowledge the Universiti Teknologi Malaysia and Ministry of Higher Education of Malaysia for their financial supports on the research grant Vot Number Q.J130000.2527.11H52.

I would like to express my very great appreciation to my beloved parents, family, siblings and friends who always be there for me during my preparation for Master Philosophy's thesis. I am particularly grateful for the encouragement, love, tolerates and emotionally supports that given by them. Surely that I was amazingly blessed with their existence in my life. Lastly, I humbly extend my thanks to everyone whom involved directly and indirectly in this journey. That said, I hereby share my favourite verses from Quran:

"…And when you have decided, then rely upon Allah. Indeed, Allah loves those who rely [upon Him]."

[QS Ali Imran:159]

"So verily, along with every hardship is relief."

[QS Asy-Syarh:5]

ABSTRACT

Flood disaster that struck east coast part of Peninsular Malaysia in 2014 caused damages and fatalities to the affected areas. During this catastrophe, Kelantan state was the most affected by flood which was rated as the worst in Malaysian history. The confluence of two rivers in Kelantan; Galas and Lebir gives high flood magnitudes to the downstream area particularly, Kuala Krai. Kelantan has no structural approach to overcome flood from occurring in this state. To address this problem, Kemubu and Lebir dams were proposed by the Department of Irrigation and Drainage (DID) to be built along Galas and Lebir rivers, as a flood mitigation measure. Development of these two dams has the potential to reduce the flood magnitude. With the availability of advanced technologies, hydrodynamic modelling can be a main tool for researchers to conduct simulation of floods. The research assessed the implementation of the proposed dams at the upstream area to reduce flood hazard in Kelantan using the hydrodynamic modelling approach. These dams were simulated at the upstream area along Galas and Lebir rivers by using the characteristics defined according to the Unit Perancang Ekonomi Negeri Kelantan report. Meanwhile, the flood events with and without these dams were observed at the downstream area particularly in Kuala Krai by simulating the 2014 flood event and different return periods. The Digital Terrain Model (DTM) with 15m spatial resolution was generated by combining the Light Detection and Ranging (LiDAR) and Shuttle Radar Topography Mission (SRTM) data which were then used for the hydrodynamic modelling. The flow hydrograph and water level for 25, 100 and 200-year return periods were generated as input data for initial and boundary conditions. River cross-sections and surface roughness coefficient were also incorporated in the model. The results of maximum velocity and water depth from the hydrodynamic modelling were used to produce flood impulse and flood hazard maps at Kuala Krai. Flood simulation of Kuala Krai with the proposed dams showed that no flood would occur at the downstream based on the discharge input considered. The peak discharge of the floodwater at Kemubu dam decreased from 2,956 m^3/s to 142 m^3/s after cresting the Kemubu dam spillways. Meanwhile, no discharge was measured at Lebir dam since there was no flood water cresting at the Lebir dam spillways. The storage capacity of the Kemubu and Lebir dams was also measured. The landuse affected by flood at the proposed dams and Kuala Krai area were identified by overlaying the flood extent map with 2013 landuse map obtained from Department of Agriculture (DOA). By having the Kemubu and Lebir dams, the oil palm and forested areas would be the worst affected. Rubber was the most affected landuse at Kuala Krai area. Validation was done by comparing the flood depth at Kuala Krai town obtained from the simulation against field survey data by researchers from Disaster Prevention Research Institute, Kyoto University, Japan and DID. Validation revealed that the average flood depth difference was 3.85m with the Root Mean Square Error (RMSE) value of 4.63m. Based on the findings, it is suggested that a higher accuracy of DTM should be used as the primary input for the flood model and be taken into consideration to improve the RSME value.

ABSTRAK

Bencana banjir yang melanda bahagian pantai timur Semenanjung Malaysia pada 2014 telah menyebabkan kerosakan dan kematian di kawasan terjejas. Semasa malapetaka ini, negeri Kelantan adalah yang paling terjejas oleh banjir yang dinilai sebagai paling teruk dalam sejarah Malaysia. Pertemuan dua sungai di Kelantan; Galas dan Lebir memberi magnitud banjir yang tinggi ke kawasan hiliran terutamanya, Kuala Krai. Kelantan tidak mempunyai pendekatan berstruktur untuk mengatasi banjir daripada berlaku di negeri itu, Untuk menangani masalah ini, empangan Kemubu dan Lebir dicadangkan oleh Jabatan Pengairan dan Saliran (JPS) untuk dibina di sepanjang sungai Galas dan Lebir, sebagai langkah tebatan banjir. Pembangunan kedua-dua empangan ini mempunyai potensi untuk mengurangkan magnitud banjir. Dengan adanya teknologi yang canggih, pemodelan hidrodinamik menjadi alat utama kepada penyelidik menjalankan simulasi banjir. Kajian ini menilai pelaksanaan empangan yang dicadangkan di kawasan hulu bagi mengurangkan bahaya banjir di Kelantan dengan menggunakan pendekatan pemodelan hidrodinamik. Empangan-empangan disimulasikan di kawasan hulu di sepanjang sungai Galas dan Lebir dengan menggunakan ciri-ciri yang ditentukan mengikut laporan Unit Perancang Ekonomi Negeri Kelantan. Sementara itu, kejadian banjir dengan dan tanpa empangan-empangan dilihat di kawasan hiliran terutamanya di Kuala Krai dengan mensimulasikan peristiwa banjir 2014 dan tempoh ulangan yang berlainan. Model Paramuka Bumi Berdigit (DTM) dengan resolusi ruang 15m telah dihasilkan dengan menggabungkan data Pengesan Cayaha Bertakat (LiDAR) dan Misi Topografi Radar Ulang-Alik (SRTM) yang kemudiannya digunakan untuk pemodelan hidrodinamik. Aliran hidrograf dan paras air untuk tempoh ulangan 25, 100 dan 200 tahun dijana sebagai data masukan untuk keadaan permulaan dan sempadan. Keratan rentas sungai dan pekali kekasaran permukaan juga dimasukkan dalam model. Hasil halaju maksimum dan kedalaman air daripada pemodelan hidrodinamik digunakan untuk menghasilkan peta dorongan banjir dan bahaya banjir di Kuala Krai. Simulasi banjir Kuala Krai dengan empangan yang dicadangkan menunjukkan tiada banjir berlaku di hilir berdasarkan input pelepasan yang dipertimbangkan. Pelepasan puncak air banjir di empangan Kemubu berkurang daripada 2,956 m^3/s kepada 142 m^3/s selepas memuncaknya alur limpah empangan Kemubu. Sementara itu, tiada pelepasan diukur di empangan Lebir memandangkan tiada air banjir yang memuncakkan alur limpah empangan Lebir. Keupayaan penyimpanan empangan Kemubu dan Lebir juga diukur. Guna tanah yang terjejas oleh banjir di kawasan empangan dicadangkan dan Kuala Krai dikenal pasti dengan menindih peta kawasan banjir dengan peta guna tanah 2013 yang diperoleh daripada Jabatan Pertanian (DOA). Dengan adanya empangan Kemubu dan Lebir, kawasan kelapa sawit dan berhutan akan menjadi kawasan yang paling teruk terjejas. Getah paling terjejas di kawasan Kuala Krai. Pengesahan dibuat dengan membandingkan kedalaman banjir di bandar Kuala Krai yang diperoleh daripada simulasi terhadap data kerja lapangan oleh penyelidik daripada Institut Penyelidikan Pencegahan Bencana, Universiti Kyoto, Jepun dan JPS. Pengesahan mendedahkan bahawa purata perbezaan kedalaman banjir ialah 3.85m dengan nilai Min Selisih Punca Kuasa Dua (RMSE) sebanyak 4.63m. Berdasarkan penemuan, dicadangkan bahawa ketepatan DTM yang lebih tinggi harus digunakan sebagai input utama model banjir dan dipertimbangkan untuk meningkatkan nilai RMSE.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

m	-	metre
m/s	-	Metre per Second
m^2/s	-	Square Metre per Second
m^3	-	Cubic Metre
m^3/s	-	Cubic Metre per Second
mm	-	Millimetre
Mm^3	-	Million Cubic Metre
N	-	Northing
n	-	Manning's Roughness Coefficient
Q	-	Discharge through the channel
Q_{peak}	-	Peak Discharge
R	-	Hydraulic Radius
R^2	-	R-squared
S	-	Channel Slope
T	-	Return Period
v	-	Velocity
α	-	Scale
β	-	Location

CHAPTER 1

INTRODUCTION

1.1 Background of The Study

Generally, natural disaster is an event that is caused by the activity of the earth. For example, the movement of the earth leads to earthquakes, tsunami or volcanic eruption while hurricanes or tornados occur resulting from unpredictable weather related to natural disaster. The consequence of extreme weather event has contributed to landslides, flood and other geologic process (Evans, 2011). Such disasters have been described by Hussain and Ismail (2013) as an unexpected event or phenomenon where its occurrence is without warning and capable to cause damage and loss of lives.

Natural disasters are not an isolated event that must be confronted by people since it is quite impossible to resist the occurrence of such event. The occurrence of natural disaster is repeated but occasional. Thus, one should not be surprised when such a disaster occurs. This event is the result of natural systems that have existed for eons, although they may be worsened through modern human activities (Harrison and Williams, 2016). Furthermore, Kongsomsaksakul *et al.* (2005) state that natural disaster can be predicted under some level of certainty but not accurately. The impact of disasters can be dissimilar because it relies on the disasters' intensity and coverage area (Khan *et al.*, 2014).

Flooding is one of the natural disasters that are most commonly faced by countries all over the world. Malaysia is one of the countries that is not exempt from flood. Although Malaysia has less exposure to some disasters like earthquakes, hurricane or tsunami, this country frequently experiences a severe flood. In fact, flood has become a primary hazard in Malaysia.

Flooding issues have arisen since 1971, where many areas were found to be affected by flood, which resulted in the establishment of the Natural Disaster Management and Relief Committee (NDMRC) by National Security Council (NSC) in 1972. NDRMC is intended to coordinate flood relief operation at every stage of national, state and district levels aimed toward preventing human loss life and reducing the damage from flood event (Khalid and Shafiai, 2015). In Malaysia, the flood relief operations are usually coordinated by NDMRC at three levels, which are national, state and district level. However, a series of catastrophic incidents in this country, especially the monsoon floods in 2014, has resulted in massive destruction in several states. As a result, the Cabinet of Ministers decided on 26 August 2015 that the planning and implementation machinery be streamlined with the establishment of the National Disaster Management Agency, also known as NADMA, to be placed under the Prime Minister's Department. The establishment of NADMA is very timely in framing a new strategy of national disaster management in order to be managed more efficiently, effectively and to every layer of society especially the disaster victims (*Agensi Pengurusan Bencana Negara*, 2015).

The flood disaster management is based on the NSC Directive No. 20 and Fixed Operating Regulations (PTO), which describes the allocation of responsibilities in managing disaster and determines how the various government and non-government agencies should participate to manage the disaster (Tahir *et al.*, 2016). Figure 1.1 showed the structure of Malaysia Disaster Management in accordance to NSC Directive No. 20. The structure conveys each level of committee from federal, state to district committee, each with their own responsibilities that directly involve disaster relief and management.

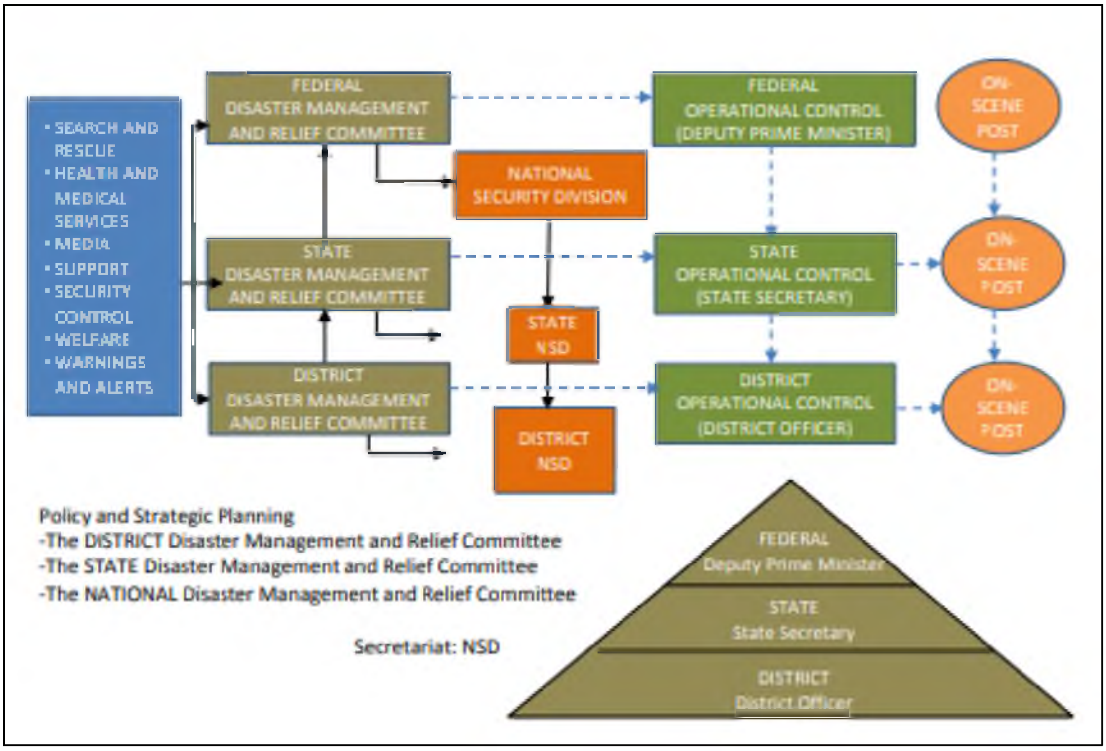

Figure 1.1 Malaysia Disaster Management Structure (Source: CFE-DM, 2016)

Figure 1.2 shows the flood prone areas in Peninsular Malaysia (DID, 2013), which are mostly located along the coastal plains in addition to locations situated near densely populated rivers and developed areas. Most of the world's earliest civilizations started where humans invariably settled near the coastlines and river valleys, which continues until today, thus humans' desire can be attributed to most of the flood destruction. In this present day, the tendency is for developers to aggressively develop the wetland areas that would otherwise act as natural flood buffers, further aggravating the problem (Zakaria *et al.*, 2017)

Figure 1.2 Flood Prone Area In Peninsular Malaysia (Source: DID, 2013)

Since Malaysia is a flood prone country, especially the east coast states, avoiding the flood catastrophe is impossible. For that reason, one has to live with the disaster by reducing the impact of the flood event. Reducing the flood hazard can be accomplished by two approaches, which are structural and non-structural (DID, 2012; Rahman, 2006). The structural measure is a conventional measure that focuses on the engineering works such as construction of levee, dam, river improvement, with the intention to control flood and enhance relief efforts. Recently, the flood mitigation in Malaysia has deviated from conventional measures, which involves high cost and places greater concern on combining the structural and non-structural measures (Ghani *et al.,* 2012).

Nowadays, the rapid advancement of satellite based technologies, spatial data analysis and modelling from time to time have created opportunities for researchers to develop accurate flood risk models in which flood management can be handled more wisely (Islam, 2014). The mandate to build structures that function as flood resistance has been given to various government agencies, which resulted in massive engineering efforts to mitigate and redirect inevitable flood. Moreover, highly advanced computer modelling and efficient flood mapping now provide disaster authorities with incredibly accurate predictions of where and how severe the floods are likely to occur (Zakaria *et al.*, 2017). Numerous hydrodynamic models such as HEC-RAS, MIKE 21, TUFLOW 2D and SOBEK have been developed to model the flood event. The flood model also can be in 1-D, 2-D, 3-D and coupled 1D2D. The results obtained from flood simulation will provide better understanding of flood behaviour so that the flood management and flood mitigation can be done in more efficient way.

Today, there is a great demand for accurate spatial and temporal information on the possible hazards and risks of flooding, especially in Kelantan, as the state is affected by flood every year. The most recent incident of 2014 flood, which hit several states in Malaysia, has caused severe damages where it has costed Putrajaya and the state government over RM 1 billion. The cost of damages for some of the states affected by this flood is shown in Figure 1.3. It shows that the cost of damages for east coast states is the highest where it costed as much as 204 million.

Num.	States	Cost of Damages (RM)
1.	Kelantan Pahang Terengganu	204 million
2.	Johor Melaka Negeri Sembilan	78 million
3.	Perak Kedah Perlis	55.6 million

Figure 1.3 Table on cost of damages according to the states affected by 2014 flood obtained from Public Work Department (JKR) source (Source: Akash and Doraisamy, 2015)

Some parts of the Malaysian economy have been adversely affected by 2014 flood, particularly in agricultural sector. The flood has disrupted Malaysia in exporting supplies to other countries due to escalation of prices of palm oil and rubber. The production of rubber in Thailand and Malaysia is said to have fallen at least 30 percent due to the flood and the prices were predicted to continue to rise. The palm oil production has declined significantly as the floodwaters in Malaysia are not subsiding (The economic Times, 2014).

1.2 Problem Statement

In 2014, some states on the east coast of Peninsular Malaysia, which are Pahang, Terengganu and Kelantan, were hit by an extraordinary flood where the increase of the flood magnitude compared to the previous flood has caused adverse consequences to these states. During this event, Kelantan suffered the worst flood in history of the state according to the NSC (Azlee, 2015). The magnitude of flood, which was beyond expectation, exposed the difficulties in the emergency response to handle this issue. Aggravating the problem is the electricity failure had limited communication and had complicated the delivery of aid and relief supply to the areas affected by flood. The 2014 flood has resulted in a huge scale of damages to the infrastructure and houses in this state. Many houses without resilient structures located in the prone area have been damaged or even worse, were swept away by the flood. In particular, about 3,390 people were forced to evacuate to a safer place (Akash and Doraisamy, 2015).

According to Alias *et al.* (2016), the intense rainfall in December 2014 that caused the flood in Kelantan was influenced by multiple contributing factors. The combination of the annual monsoon season and the global climatic patterns have enhanced the rainfall. The torrential rainfall that began on the 17th of December, 2014, led to flash flooding in Kuala Krai, Kelantan. The second heavy rainfall episode began on 22nd December 2014 where the rainfall exceeded 150mm at Gunung Gagau station and Lembangan Sungai Golok station. The rain continued on 23rd December 2014 at Gunung Gagau station. On 24th December 2014, the rains concentrated in the middle of Kelantan river basin, which are at Kusial and Kuala Krai stations. Lastly, the rains began to subside on 25th December 2014 (DID Kelantan, 2014). Figure 1.4 shows the daily rainfall of Peninsular Malaysia on 22nd and 23rd December 2014. The storm center starts at the hilltop of the upstream river basin in Kelantan, Pahang and Terengganu as shown in the red dotted circle. The amount of rainfall received on 22nd December 2014 was 507mm.

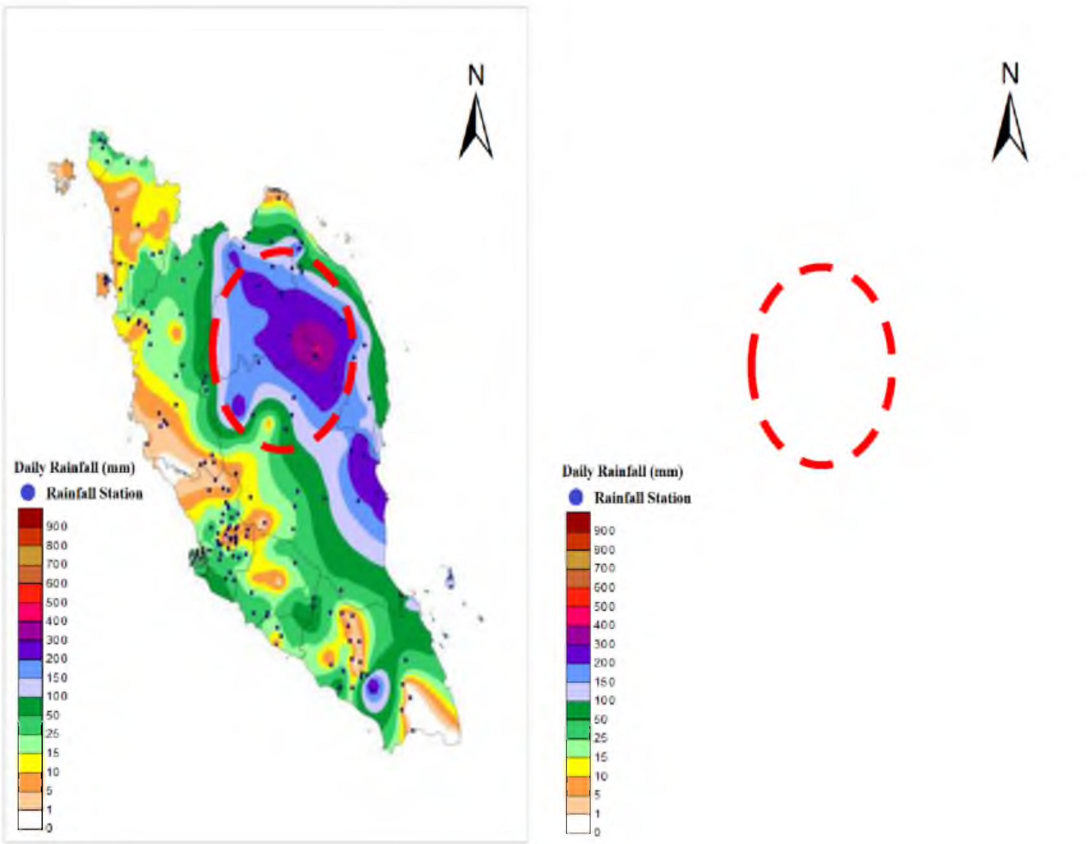

Figure 1.4 The rainfall status of Peninsular Malaysia on 22nd and 23rd December 2014 (Source: DID Kelantan, 2014)

The massive flood that occurred in Kelantan raised the idea of the development of the proposed Kemubu and Lebir dams located at the upstream area of Kelantan state by the Department of Irrigation and Drainage (DID) to control flood disaster. There is a need to build the dams at the Galas and Lebir rivers because the confluence of these two rivers emerge to form Kelantan river, which has led to great flood magnitude to the downstream area, particularly in Kuala Krai. Topographically, Kuala Krai is situated near the confluence of these two rivers, which exacerbated the problem.

Moreover, Kelantan state did not have any structural approach such as dam structure to reduce the risks of flood in comparison to Terengganu state, which operates Kenyir dam to overcome the flood issue. While, heavy rainfall in Pahang state was received only in some areas conversely for Kelantan Basin that is rampant and received heavy rainfall in almost all part of the Kelantan state. Hence, the huge water capacity causes the floods hit the entire state of Kelantan due to the accumulation of heavy rainfall in the basin starting from the upstream (DID Kelantan, 2014). Figure 1.5 shows the schematic picture that explains the location of the proposed dams and the location of the Kuala Krai which situated after the confluence of two rivers.

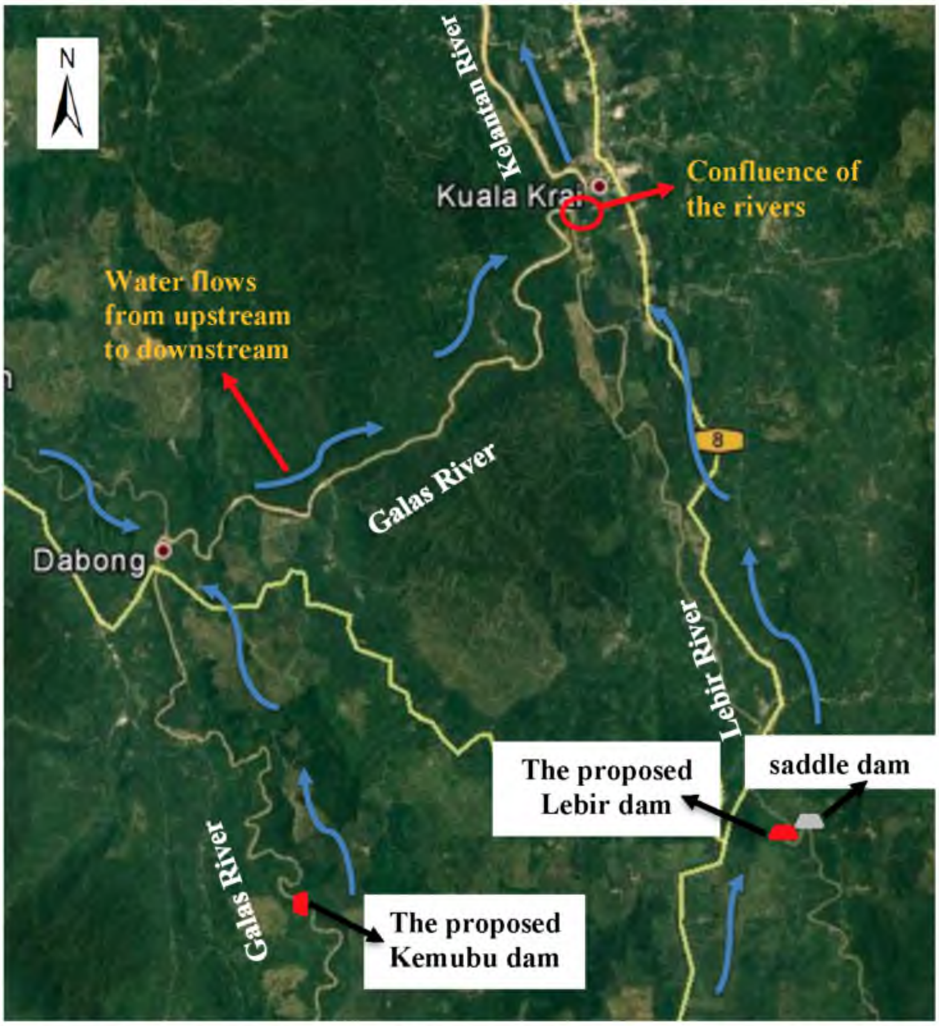

Figure 1.5 The schematic picture of the proposed dams and Kuala Krai location

National Water Resource study by Japan International Cooperation Agency (JICA), which emphasized the need to build multipurpose dams to accommodate water supplies for domestic, industrial and agricultural use, was first proposed in 1982 as one of flood mitigation. These dams were expected to solve flood problems in Kelantan. Unfortunately, this proposal was initially rejected by the state government, which considered that the area to be flooded would be too wide, and that as a result, too many people would have to be relocated if the dam were built. However, this proposal was reviewed and taken into consideration again in 1983 where the federal government requested JICA services assistance under the Japanese government technical assistance plan to study the prefeasibility of the proposed dams towards controlling and reducing the annual flood in Kelantan (UPEN, 1989). The widespread flood that occurred in Kelantan had dramatic effects, especially on the monetary misfortunes and lives experienced by this state in 2014, have again shown the importance of the development of the proposed dams at Galas and Lebir rivers, respectively.

A dam is defined as man-made barrier, together with appurtenant works where the structures are constructed intended to retain or control water or other fluid (DID, 2017). 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. Moreover, the structural works are basically very expensive and will involve a huge cost to establish. One can study the prospects especially in flood mitigation from the presence of the proposed dam before the structure works are being developed in real life. Furthermore, the flood management can be more effective and efficient by combining the structural and non-structural approaches (Mulok *et al.*, 2010).

From hydrodynamic modelling, flood mitigation planning can be constructed for preparedness in facing the flood event in future. It is necessary for the decision makers to know the magnitude of flood before any impact assessment of flood event can be initiated. Hydrodynamic modelling together with Remote Sensing and Geographic Information System (GIS) are major tools that enable different flood scenarios to be easily mapped and the risks related to the flood can be presented in timely manner (Jeb and Aggarwal, 2008). Since the flood disaster has caused a huge cost incurred by the Malaysian Government, the development of appropriate flood modelling techniques is significantly necessary as the appropriate flood mitigation strategies can be designed through it. By using the techniques of remote sensing and GIS, the overall flood management can be supported where the data collection can be prepared rapidly and analysis can be done for hydrological and hydrodynamic studies (Pradhan *et al.,* 2016).

Over the last two decades, remote sensing data has made tremendous progress in the modelling of floods. In particular, low-cost space-borne data can be precious for large-scale flood studies in an area with limited data. The numerous satellite products that provide invaluable information such as land surface elevation, flood extent and water level could possibly contribute to several flood studies. The evolution of the technology over time has also led to the enhancement of remote sensing data sources in terms of better accuracy. Among the recent data sources, the Airborne Light Detection and Ranging (LiDAR) topography is one of the remotely sensed data which offers high spatial resolution and high data accuracy. However, this data is usually very costly to acquire over large areas (Yan *et al.*, 2015). Consequently, when large-scale flood studies are undertaken, especially in urbanized area, it will depict a significant limitation. Hence, the usefulness of freely and globally available data such as Shuttle Radar Topography Mission (SRTM) topography in supporting hydraulic modelling of floods is of extremely high interest from both a scientific and engineering point of view (Yan *et al.*, 2015).

The availability of the high resolution data of airborne LiDAR has a significant contribution to flood studies. The capabilities of this data in improving the prediction of flood waters more accurately in relatively flat floodplains has facilitated the flood studies to be done appropriately. Despite the vast advantages of the airborne LiDAR data capabilities in flood studies, the acquisition process of this data always involve very high cost to be spent. Remote sensing and GIS have emerged as powerful tools to deal with various aspects of flood management in prevention, preparedness and relief management of flood disaster. GIS facilitates the integration of spatial and nonspatial data for example rainfall and stream flows, river cross sections and profiles, and river basin characteristics, as well as other information such as historical flood maps, infrastructures, landuse, and social and economic data. Such data sets are critical for the flood depth analysis and flood management (Al-Tahir *et al.*, 2014).

A significant number of researches have been dedicated to flood studies in particular for Kelantan state for the past few years based on 2014 flood event. For example, the study on flood forecasting modelling of Kelantan river basin has been done by Azad *et al.* (2016). Meanwhile the flood damage has been studied for flood hit location in Kuala Krai, Kelantan (Mar Iman and Sathiamurthy, 2016), the assessment of the influence of land cover/landuse modifications on flood event at Kelantan river basin (Saadatkhah *et al.*, 2016), rainfall-runoff modelling of the Kelantan River Basin (Basarudin *et al.*, 2014; Ghorbani *et al.*, 2016) and many other researches in flood have been carried out in recent years using numerical solution together with the advances of flood model that helps the works in flood studies to become easier. However, few studies have been dedicated to the proposed dams for Kelantan intended to reduce the flood hazard to this state besides the study previously been done by JICA and DID. The study on the proposed dams has not discovered widely in recent time, although a study for the proposed construction of two dams in Kelantan had been in a long-term plan to overcome the drought likewise flood problem in Kelantan as said by Kamal Mustapha, The Director of Department of Irrigation and Drainage Kelantan (Kamarudin, 2019). Therefore, this study discusses about the assessment on the implementation of the proposed Kemubu and Lebir dams in reducing flood hazard at the downstream area of Kelantan state by using hydrodynamic modelling approach.

1.3 Aim and Objectives

The aim of this research is to assess the implementation of the proposed dams at the upstream area in reducing flood hazard in Kuala Krai, Kelantan using hydrodynamic modelling approach. To accomplish the aim, there are three specific objectives as follows:

(a) To define and form the proposed Kemubu and Lebir dams of Galas and Lebir rivers, respectively, onto Digital Terrain Model (DTM).

(b) To simulate the flood events before and after the proposed dams for 25-year, 100-year, 200-year return periods and 2014 real flood events at the Kuala Krai area.

(c) To evaluate the efficiency of simulated proposed dams in reducing flood hazard in the study area.

1.4 Research Questions

Table 1.1 Research Questions

Aim	Objectives	Research Questions
To assess the implementation of the proposed dams at the upstream area in reducing flood hazard in Kuala Krai, Kelantan using hydrodynamic modelling approach.	1) To define and form the proposed Kemubu and Lebir dams of Galas and Lebir rivers, respectively, onto Digital Terrain Model (DTM).	1) What is the specifications used for each proposed dam? 2) What is the dam operational aspect to simulate the proposed dams? 3) Will the dam retain the flood water in preventing flood to downstream area?
	2) To simulate the flood events before and after the proposed dams for 25-year, 100-year, 200-year return periods and 2014 real flood events at the Kuala Krai area.	1) How much possible hazard occurs at the area based on 2014 flood events and different return period?

	3) To evaluate the efficiency of simulated proposed dams in reducing flood hazard in the study area.	1) Will the construction of proposed dam reduce the impact of flood hazard at the downstream area? 2) What are the hazardous elements need to be analysed?

1.5 Scope of Study

This study is comprised of several scopes regarding some limitations that have been conducted throughout this study. The scopes include the horizontal and vertical accuracies of the DTM, type of flood modelling, the design of proposed dams, the scenarios of the flood simulation as well as the limitation of the hardware and software used in this study.

i. Horizontal and Vertical Accuracies of the DTM

In this study, the DTM from airborne LiDAR data source with 3m spatial resolution is used as a primary data for hydrodynamic modelling. However, some parts of the study area are not covered by LiDAR DTM since the DTM from LiDAR data source has only covered the area along the river of Kelantan state. The cost of acquiring and processing the LiDAR data is very expensive. This is therefore a significant limitation when large-scale flood studies are undertaken. Hence, the DTM from SRTM data source with 30m spatial resolution is used to fill the remaining part of study area. The combination of LiDAR DTM and SRTM helps in assessing the extent of flood waters at the study area. The DTM from these two data sources are then resampled to 15m spatial resolution, which involves process of downgrading the DTM from high spatial resolution and vice versa from combining the DTM from two data resources with finer and quite coarse resolution. The DTM of 15m spatial resolution was used in order to cope with the SOBEK hydrodynamic model limitation because SOBEK hydrodynamic model requires a very powerful computer system in order to perform the flood simulation without problem during simulation is carried out. The DTM then undergo mosaic process in order to create a new raster by using tools in ArcGIS software. Basically, the vertical accuracy and spatial resolution of the DTM is important for flood study. The DTM with finer spatial resolution can help in producing flood maps of better accuracy. However, in this study, the vertical accuracy of LiDAR DTM is 0.15m meanwhile the vertical accuracy of SRTM data source is 16m.

ii. The integration of 1D and 2D flood modelling

Also, the flood simulation has been carried out using the integration of 1-D and 2-D SOBEK hydrodynamic model developed by Delft Hydraulic, the Netherland. A 1-D model involves each computational point corresponding to a cross section located along the river network while a 2-D model uses a finite different method for computation of the floodplain represented in each grid cell. The system of SOBEK model which integrate the 1-D with 2-D features provides better modelling flexibility and accuracy in computing water surface profile as well as inundation extent. Also, the SOBEK model is fair simply model where it uses a raster grid approach as the input data that can be manipulated through a raster based GIS system. Since the output results of SOBEK model can easily be fed into a GIS system, the further analysis of results are possible to be done as well as the visual enhancement.

iii. The scenarios of flood simulation

In this study, the flood simulations are conducted according to two scenarios. The flood simulation is divided into two scenarios due to the limitation of the computer specifications and flood model ability used in this study to simultaneously simulate the large area that include the flood of the proposed dams area together with Kuala Krai area. Hence, the first scenario is on flood simulation of the proposed Kemubu and Lebir dams. The simulation is conducted along the Galas and Lebir rivers where the proposed dams are to be located. Understandably, it is believed that the flood at the downstream area can be reduced if the proposed dams are built. The second scenario focuses on simulation of the flood at the downstream area before and after the implementation of the proposed dams. The concentration was in Kuala Krai area particularly at the area after the confluence of Galas and Lebir rivers since this area was the most affected by flood in 2014. The confluence of Galas and Lebir rivers at Kuala Krai causes a huge amount of flood waters to the downstream and cause massive damages to this area. Thus, the flood simulation was conducted on 2014 flood event and with different magnitudes of flood, which are 25-year, 100-year, 200-year return periods to predict the worst case scenarios for the proposed dams.

iv. The Simplification of The Proposed Dams Design

The most important thing that must be taken into consideration in this study was on the dam operation. In this study, the simulation of the proposed dams has been carried out by using simplification as simple as by adjusting the elevation of the DTM to the spillways and the dam crest elevation that have been defined according to previous report UPEN (1989).

v. The Limitation of the Software and Hardware

This study also has software and hardware limitations. The SOBEK model requires high-performance computer so that the flood simulation can be done efficiently. In this study, the flood modelling has been carried out using computer with specifications as shown in Table 1.2. By using this computer specification, the study area for the proposed dams and Kuala Krai area has been covered less widely since the input DTM with greater numbers of pixel will contribute to longer time computation.

Table 1.2 Specifications of the computer system

System	Specification
CPU	Intel (R) Core (TM) i7-3770, 3.4 GHz
RAM	16.0 GB
Operating System	Microsoft Window 7
System Type	64-bit Operating System
Graphic Card	NDVIA GEFORCE GTX 550 Ti
Memory Storage	1.8 Terabyte

Moreover, the period to simulate the flood event for the proposed dams have been shortened to accommodate the limitation in SOBEK model. This is because the flood simulation using this model was quite time consuming and the excessive processing can cause an error to be occurred during simulation. Therefore, the time step for each flood simulation in this study was defined as one hour. The number of days designed for flood simulation of the proposed dams is simulated for three days. Meanwhile, flood simulation for Kuala Krai area is conducted for 15 days with the hourly time step. The definition of the time step in flood modelling is important because the larger time step can cause the flood model to become unstable and the simulation will not run until it finished or will generate inaccurate results. Whereas, the smaller a time step takes longer time for simulation to be run.

1.6 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. With total area of 15,009 km^2, Kelantan state comprises a population of 1,718,200. It consists of ten administrative districts which are Kota Bharu as a capital city, Tumpat, Bachok, Pasir Mas, Tanah Merah, Jeli, Machang, Pasir Putih, Kuala Krai and Gua Musang (DID, 2011)

Kelantan River Basin has a tropical climate. It has minimum temperature of 23°C to maximum temperature of 33 °C and receives rainfall throughout the year. The maximum annual rainfall of Kelantan can reach approximately 1750mm during the monsoon season from November to January (MMD, 2018).

There are six major sub-basins in Kelantan River basin namely Galas, Nenggiri, Pergau, Guillemard Bridge, Kuala Krai and Lebir. Kelantan river is a major water resource for this state. This river emerges at the confluence of its two main tributaries, Galas and Lebir rivers, before its transforms to a broader stream with mud-colour. Then, it meanders over the coastal plain until it reached northward into the South China Sea, which is about 12 km north of Kota Bharu. Galas river flows starting from the merge of Nenggiri river which is rising high on the slope of Gunung Korbu, the second highest peak in Peninsular Malaysia. The Lebir river source initiated in the wilds of Taman Negara National Park. Each river has many tributaries.

Kuala Krai area formed as a hilly land area. Prior to the 20^{th} century, the entire area was tropical rain forest. With improvement in transportation links during 20^{th} century, settlements became established along the railway routes in Kuala Krai territory where the main activities for population in this area was agriculture. The area of Kuala Krai catchment is 2,329 km^2 shown as the red boundary on the map below where it comprises about 104,356 of population in 2010 with the density is 45/km^2. Figure 1.6 shows the location of study area. Therefore, this study focuses on the upstream area, which are Galas and Lebir rivers, respectively, where the area of Kemubu dam and Lebir dam has been proposed to be located. Then, the flood was observed at the downstream area particularly at Kuala Krai.

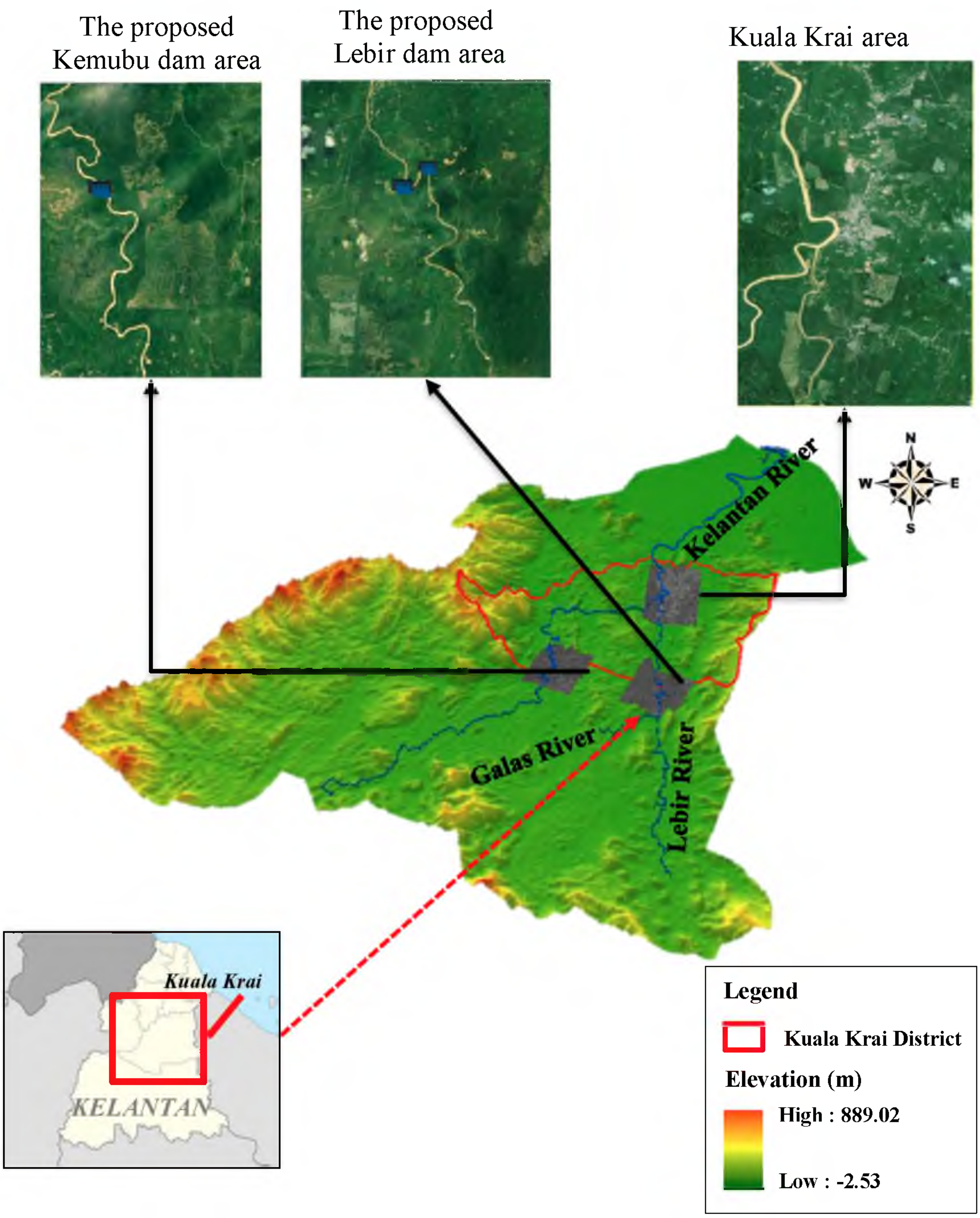

Figure 1.6 Location of Study Area

1.7 Significance of the Study

Flood disaster normally leads to adverse consequences, affecting the communities, infrastructure, environment and individual according to the severity level of the flood event itself, in particular, to the flood prone area tagged by some elements which have great exposure to flood hazard. As can be seen from 2014 flood that hit several states in east coast part of Peninsular Malaysia, the flood disaster has resulted in massive damage. This flood issue has drawn attention from various levels of committee from various agencies to launch the relief aid mission for the flood victims as well as to encounter the flood problem in this country. In addition to providing benefits toward the minimal costs involved by using non-structural approaches in reducing the flood risks to Kelantan state, this study also has guided the respective authorities to practise the sustainability development in order to protect the environment. The finding from this study can help the government in framing strategies either in flood mitigation, or even in improving sustainable of human welfare in terms of economically viable, socially equitable and environmental sustainability by the implementation of the proposed dams.

Furthermore, the findings of this study would benefit various government or non-government agencies including UPEN, Kelantan. The finding of this study would benefit UPEN because it was carried out as a continuation of the previous flood mitigation plan by JICA which then has been reported in UPEN report. The advances of flood model and recent high resolution topography data that have been used in this study helps UPEN in planning the flood mitigation for Kelantan by implementation of the proper flood retention more accurately to real life. In addition, the finding of this study also benefits other agencies such as DID, NSC, Social Welfare Department (JKM), JKR and also the private sectors, Non-Governmental Organization (NGO) and society. The flood maps produced from the results of hydrodynamic modelling can be used by any respective agency so that contingency plans can be made. Generation of flood hazard map can be very useful as guidance for the preparedness and management plan for the expected flooded area. For example, the flood hazard map helps DID in enhancing the existed flood forecasting and flood warning system. Moreover, the dissemination of flood information can be made by DID to the people at the affected areas as an early warning so as to reduce the number of fatalities.

The other agencies, for instance NSC and JKM, can also use the findings of this study to manage the rescue of flood victims or to suggest alternative evacuation routes if existing roads are inundated, and cater to the welfare of the victims. Meanwhile, in reducing the damage to properties such as the road, bridges and any structural works due to flood occurrence, the results of flood simulation for different magnitude in this study would benefit JKR in assessing the hazard for different return period in enhancing the structural works toward development of more resilient infrastructure to overcome the flood hazard. Additionally, flood maps are usually important for any private agencies like insurance companies since it can be used to estimate monetary losses due to flood event. Next, the evacuation centre with applicable capacity to accommodate the flood victims can also be designed by identifying the flood extent obtained from flood simulation by respective agencies or NGO in future so that more lives and property can be saved from flood disaster. The flood hazard maps are correspondingly significant to real estate agency since the market value of the property can be determined from it. It is vital for real estate seller to know flood zone area of their property as the seller is required to disclose all facts that are material which can possibly affect the price paid and desirability by a potential buyer.

This study would also benefit the local people in Kelantan, especially the residents of Kuala Krai area. Flood hazard map can be used to enhance the awareness of flood disaster to people so that they have better understanding due to the impact of flood disaster. Hence, dissemination of the importance of flood disaster preparedness and notifying the local people of the potential flood damage can help these people to be more ready in facing the risks of flood.

1.8 Thesis Structure

This thesis consists of six chapters which are as below:

Chapter 1: Introduction

In Chapter 1, preliminary study on research topic are discussed such as background of the study, problem statement, aim, objectives, research questions, scopes of the study, area where the study is to be conducted and the significance of the study. Detailed explanations and understandings were put forward in driving the whole research in this chapter.

Chapter 2: Literature Review

Chapter 2 focuses on literature review related to this research. The purpose of this chapter is to give background information needed for a better understanding of the research that has been carried out. Several topics are discussed such as flood disaster, the concept of flood hazard, vulnerability and risk, flood mitigation, flood hydrodynamic modelling, hydrodynamic model used in Malaysia, SOBEK hydrodynamic model and flood frequency analysis.

Chapter 3: Research Methodology

Chapter 3 concentrates on the method used to accomplish the aim and the objectives in this research. This research consists of five main phases such as data acquisition, pre-processing (model schematization), flood simulation, generation of flood hazard map and assessment.

Chapter 4: Results and Discussion

This chapter discusses the results obtained from the flood simulation of the proposed Kemubu and Lebir dams and the results of flood simulation of Kuala Krai before and after the development of the proposed dams. The results are in different return periods which are 25-year, 100-year, 200-year return periods and 2014 floods. The assessment for results obtained are discussed. Where the comparison of the declining flood rate before and after the development of the dams are measured. Then, the flood extent map for the proposed dams are produced and the inundated area are measured. The estimation of the dam storage capacity for both proposed dam are measured. Also, the map of flood impulse and flood hazard map at Kuala Krai is produced and the landuse of the area affected measured. The efficiency of the proposed dam in reducing the flood hazard are discussed in this chapter.

Chapter 5: Conclusion and Recommendation

This chapter summarizes the objectives in this research and discussed the findings of the research. Some recommended directions for future study are presented after concluding the findings.

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