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Projection Floods Under Future Climate in the Kelantan River Basin, Malaysia

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Abstract: Flood projection is considered one of the most powerful tools for locating an area in high-risk flood zone especially with the impact of climate change. The digital elevation model (DEM) is an essential input of hydrological modelling to establish flood hazard projections. The accuracy of river flow calculations directly depends on the scale and accuracy of topographic maps. One of the purposes of this study is to develop the flood hazard projection under climate change in Kelantan River Basin by using the Geographic Information System (GIS) and hydrologic-hydrodynamic models with available data. Kelantan River Basin, Malaysia was selected due to its repetitive flood events. In the future, Pasir Puteh, Bachok and Kota Bharu may be subjected to greater flooding hazards.

Keywords: Statistical Downscaling Model, Flood Modelling, Hydrological Modelling, Hydrodynamical Modelling, Kelantan River Basin

1. Introduction

Floods are reported to have contributed to most of the world's natural disasters, and this proportion has been increasing over the past 30 years to the present [1]. Hence, the development and application of flood modelling and related research have become a global venture. A flood study is an essential measure for understanding and managing flood events, whether they are in large-scale rural areas, developed urban areas, or property and infrastructure development. To date, two flood modelling approaches has been recognized which are empirical methods (such as remote sensing, surveys, measurement, and statistical models developed from data-based methods) and hydrodynamic models [2].

Advanced technologies have been developed to collect, integrate, process, and analyse data related to floods. For instance, remote sensing data has made remarkable progress in the last two decades in flood modelling [3]. The remote sensing data are also known as "observations". So, this type of modelling, which is the past observation, is considered robust and accurate. Thus, these approaches need to be adopted in reducing the impact of flood problems in Malaysia especially in Kelantan River Basin.

Kelantan River is one of Malaysia's major rivers that floods every year [4]. Due to many factors, flood events at Kelantan River have shown more disastrous in the last decade. Recent devastating flooding events in Kelantan were recorded in December 2014 and January 2015, with flood levels, reaches up to 5 to 10 meters. This "Kelantan Big Yellow Flood 2014" affected more than 100,000 people, and the flood damage was estimated at around RM 1 billion [5].

One possible primary reason for these changes is unpredictable climate change. Climate changes will have direct and indirect effects on human societies and the natural environment. This scenario will impact hydrology and water resources because they are closely related to climate. According to [6], global hydrological cycles are anticipated to change rapidly caused by climate change. For instance, previous study by Tan [7] projected annual rainfall to increase in Kelantan by 1.2-8.8%. Their projection also expected to rise such as evapotranspiration (0.3 - 2.7%), surface runoff (46.8 - 90.2%) and annual streamflow (14.6 - 27.2%).

It is not possible to avoid the risk of flooding or prevent the disaster, but it is necessary to minimize the impact and losses caused by the floods. Therefore, it is essential to learn

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the relationship between climate change and water response [8].

2. Material and Methodology

2.1 Study Area

The study area is the Kelantan State (Fig 1). Kelantan River Basin has a long history of severe flooding due to the high rainfall intensity. Syafrina [9] explained that the climate of Kelantan River Basin is a tropical climate with high temperatures and high humidity. The mean annual temperature recorded is approximately 27.5 °C, and the annual mean rainfall is more than 2500 mm.

The Northeast Monsoon (NEM), which lasts from November to February, brings substantial rainfall to the Kelantan River Basin region. The southwest monsoon (SWM) starts in May and ends in late August with less precipitation. As a result, the state has its wettest period during the wet season which is the NEM period and the drought season during SWM. According to Nashwan [10], the annual mean runoff for the Kelantan River Basin is approximately 557.5 m^3/s.

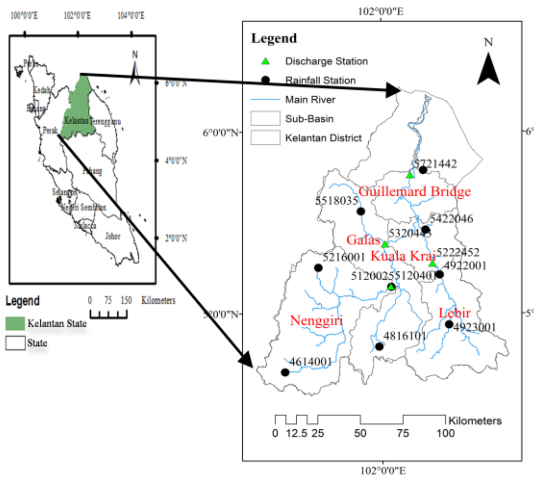

Fig. 1 - Identification of study area

2.2 Data Collection and Methodology

The observed daily rainfall and discharge datasets at four discharge stations (Table 1) and nine rainfall stations (Table 2) as shown in Fig. 1 were provided by the Department of Irrigation and Drainage (DID), Malaysia for the period 1990–2018. Additionally, the National Centre for Environmental Prediction (NCEP) reanalysis dataset and Representative Concentration Pathways (RCPs) were obtained for the purpose of model calibration and validation. Likewise, two sets of 26 large-scale predictors derived from CanESM2 (NCEP, RCP 2.6 and 8.5) were selected for the sake of scenario generation for the 2020s (2011–2040), 2050s (2041–2070) and 2080s (2071–2100). The RCP Scenarios considered in this study are chosen based on the lowest (RCP 2.6) and highest (RCP 8.5) scenarios of greenhouse gases that have been recently examined by the climate research community.

Table 1 - Discharge stations for analysis

Sub-Basins	Station No.	Station Name	Lat. (o ' " N)	Long. (o ' " E)
Nenggiri	5120401	Nenggiri River at Bertam	05 08 55	102 02 45
Galas	5320443	Galas River at Bukit Apit Dabong	05 22 55	102 00 55
Lebir	5222452	Lebir River at Kg. Tualang	05 16 30	102 16 00
Guillemard Bridge	5721442	Kelantan River at Guillemard Bridge	05 45 45	102 09 00

Table 2 - Rainfall station for analysis

Sub-basin	Station No.	Station Name	Lat. (o ' " N)	Long. (o ' " E)
Nenggiri	4614001	Brook	04 40 35	101 29 05
	5216001	Gob	05 15 05	101 39 45
	5120025	Balai Polis Bertam	05 08 45	102 02 55
Galas	4816101	Redip	4 49 00	101 59 00
	5518035	Sek. Keb. Lubok Bungor	05 33 40	101 53 20
Lebir	4923001	Kg. Aring	04 56 15	102 21 10
	4922001	Kg. Lebir, Paloh	05 12 45	102 18 15
Kuala Krai	5422046	Ldg. Lepan Kabu	05 27 35	102 13 50
Guillemard Bridge	5722057	Jps Machang	05 47 15	102 13 10

This study focuses on the projection of future rainfall corresponding to climate change by using the downscaling method of Statistical DownScaling Model (SDSM) and flood hazard projection, which involved hydrologic and hydrodynamic modelling by using Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) and Hydrologic Engineering Centers River Analysis (HEC-RAS), respectively. Finally, by integrating the SDSM projection with the HEC-HMS and HEC-RAS models, the study produced flood hazard projection with the impact of climate change. The framework of the study is shown in Fig 2.

Downscaling model of SDSM was built to accurately simulate the effects of climate change based on RCP scenarios to the Kelantan River Basin region. The trend and pattern of rainfall changes were assessed by comparing the projected rainfall with the current rainfall. The projection of daily rainfall was developed for 90 years period (2011-2100), which three future periods are considered: the 2020s (2011-2040), 2050s (2041-2070) and 2080s (2071-2100).

Following the developed hydrological model after calibration and validation with HEC-HMS, the discharge simulation based on climate change is carried out. HEC-HMS uses generated future rainfall computed by the SDSM model that has been well validated as described to predict future discharge. The last part of this study simulates the flood hazard projection based on climate change by using the HEC-RAS model. In this case, the projected future discharge from the HEC-HMS model is the input to the HEC-RAS model as the boundary condition. The HEC-RAS modelling requires the

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discharge projection data upstream of the Kelantan River Basin. Thus, peak hydrograph event and flood inundation projection for the RCPS 2.6 and 8.5 can be generated for the Kelantan River Basin.

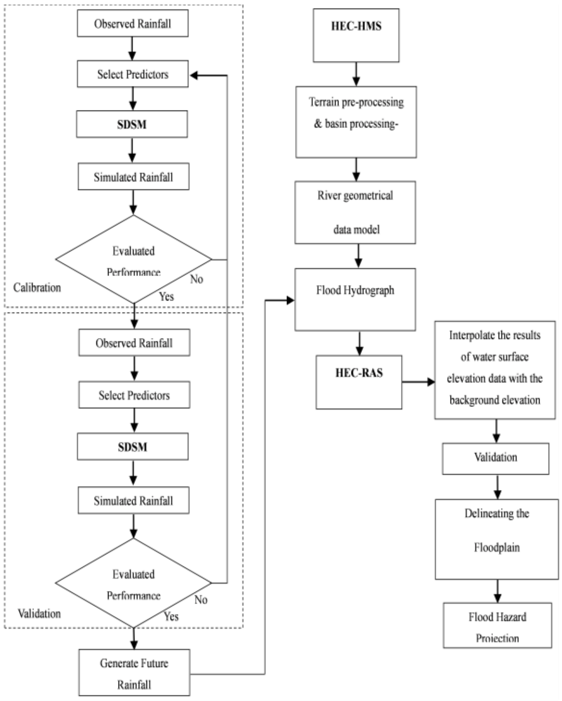

Fig. 2 - Research design of the study (Bold text indicated the main models).

3. Result and Discussion

3.1 Downscaling Corresponding to Future Climate Scenarios

Table 3 shows the percentage of future annual mean changes in rainfall, in the 2020s, 2050s, and 2080s relative to the observed period (2006-2018) under the CanESM2, with RCP 2.6 and 8.5 scenarios obtained from SDSM. In terms of temporal change, the annual mean rainfall under the two RCPs scenarios demonstrates decreasing trend for all periods. The most significant decrease rate is -75.97% under RCP 8.5 in the 2080s at Station 5120025. While only Station 5718033 showed a slight increase in the percentage of annual mean rainfall in the 2020s. The location of these two rainfall stations indicates that climate changes in the upper basin are more significant than those in the lower basin throughout all periods.

These findings contradict the study from Tan [11], in which their finding shows that the rainfall trends are increasing in Kelantan River Basin. The reason for these discrepancies is not obvious. Still, the SDSM model uses multiple predictor variables on a large scale, which could explain the difference in downscaled rainfall in representing spatial variability of rainfall precipitation on this large watershed.

Table 3 - Percentage changes in annual mean rainfall in the future compared to the observed period (2006-2018) in the Kelantan River Basin

Station No.	2020s (%)	2050s (%)	2080s (%)
RCP 2.6			
4614001	-14.34	-18.15	-18.11
4819027	-37.61	-41.18	-39.93
4923001	-36.47	-36.11	-32.15
5120025	-43.56	-54.49	-47.75
5216001	-39.47	-38.40	-41.74
5322044	-28.14	-33.00	-35.45
5521044	-42.16	-41.37	-43.77
5718033	0.54	-0.82	-1.76
5722057	-46.19	-50.00	-50.41
RCP 8.5			
4614001	-12.73	-12.06	-11.01
4819027	-40.79	-43.22	-40.95
4923001	-37.54	-40.12	-37.31
5120025	-49.40	-67.29	-75.97
5216001	-41.54	-42.53	-44.36
5322044	-30.32	-38.23	-41.16
5521044	-45.41	-46.10	-41.88
5718033	0.96	-4.05	-1.96
5722057	-52.38	-52.45	-53.33

3.2 Projection of Daily Peak Discharge using HEC-HMS

The Guillemard Bridge station is focused because the station is located at the downstream area, which is the hotspots area for flooding. Fig. 3 display the projected peak discharge at Guillemard Bridge under the two RCP scenarios relative to 2014 flood event discharge. Most of the projection from RCPs in the three-time periods anticipated plus/minus peak discharge compared to the magnitude from the 2014 peak flood. This shows that the extreme hydrological event in either scenario in the future was comparable to the 2014 flood event, known as one of the worst flood disasters recorded at Kelantan River Basin for the past decades [12].

Ghazali and Osman [13] reported that in the December 2014 flood disaster, the entire damage cost to property, infrastructure and agriculture was reported to be exceeded RM 1 billion, with 14 deaths and 319,156 people evacuated. The highest peak discharge projection at Guillemard Bridge was simulated by RCP 2.6 in the 2020s with 23812.7 m^3/s. Finding also highlight that the capacity of the Kelantan River at the downstream floodplain is less than 10,000 m^3/s. Therefore, floods that exceed this capacity will overflow the banks, inundating land surface areas and eventually flowing into the sea. More than 20 floods have occurred since 1965, exceeding the capacity limit.

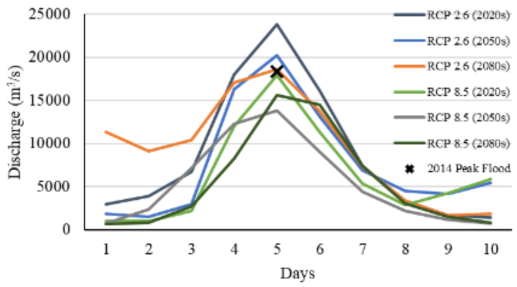

Fig. 3 - Projected peak discharge at the Guillemard Bridge at the downstream basin under climate change.

3.3 Future Flood Projection under RCP Scenarios

The study focuses on the flood hazard simulation until 2100 at the downstream area. The downstream of Kelantan River Basin consists of five (5) main districts region: Pasir Puteh, Pasir Mas, Bachok, Tumpat and Kota Bharu. The boundary flow conditions of the HEC-RAS model were determined using the discharge simulated under RCP scenarios from the upper sub-basin of the Kelantan River Basin, which are at Nenggiri, Galas and Lebir. As a result, Fig. 4 depict the flood exposure for each RCP scenario according to the three periods. In general, the outcomes show that the flood hazard appears to be increasing in the future for all RCPs scenarios. Furthermore, the flood hazard level varies significantly on the west and east corners of the basin, especially in the southeast area with the highest overflow.

For RCP 2.6, the maximum runoff was 13891.87, 13424.40, and 14542.29 m^3/s for the 2020s, 2050s and 2080s, respectively. Fig. 4(a,b,c) depicts the affected area of the Kelantan River Basin simulation. The figure shows that the inundated areas were almost the same for the three periods. However, slight larger inundated areas were simulated during the 2080s, with greater flood depth. Observations have revealed that the edge of Pasir Puteh and Bachok region are the most susceptible to flooding (highlighted in circles on the first inundation projection). At the left side of Guillemard Bridge, the flood depth is simulated between 0-8.9 metres, while the maximum flood depth recorded at the right side of the river is 11.6 metres. The main inundated areas from the HEC-RAS are consistent with those reported by Mohammadi [15]. Both studies showed that these regions are the most susceptible region to flood disasters downstream of Kelantan River Basin.

RCP 8.5 generated a maximum runoff of 16372.20, 21508.70, and 16733.38 m^3/s during the 2020s, 2050s and 2080s, respectively. The RCP 8.5 shows the highest spatial coverage of the flooded area compared to the RCP 2.6 scenario for all periods. As shown in Fig. 5(e), the generated flood projection for the RCP 8.5 scenario at the 2050s established the greatest inundated area compared to all other periods from RCP scenarios, where practically all adjacent populated regions were vulnerable to flooding.

A similar flood hazard projection was also projected in Kelantan River Basin using 100 years Average Recurrence Interval (ARI) Design Flood [14]. Although the created flood hazard projection may not be accurate, it may be used to update current and future flood hazard information, which can then be utilised as input for flood risk assessment and mitigation. It may be used, for example, to mitigate floods caused by climate change by implementing a good risk management approach. Specifically, the model developed for this study helps predict runoff volumes and flooding in the study area.

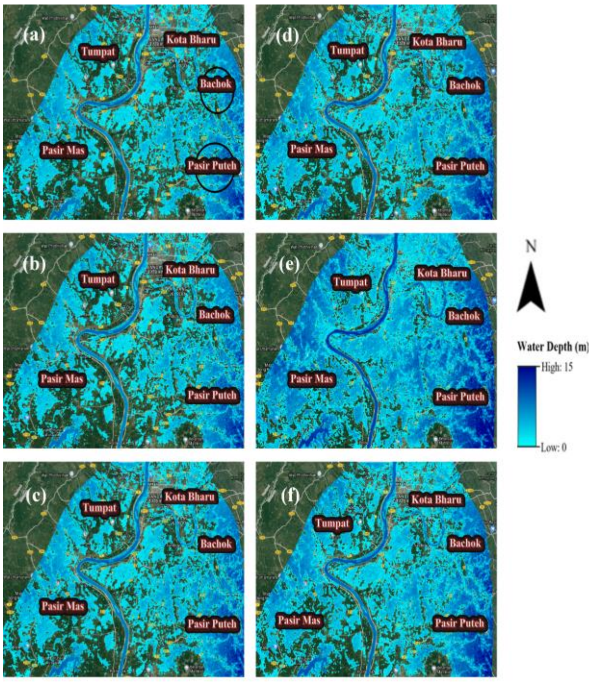

Fig. 4 - Flood extent projection for RCP 2.6 in the (a) 2020s, (b) 2050s (c) 2080s and RCP 8.5 in the (d) 2020s, (e) 2050s (f) 2080s.

4. Conclusion

The findings of the study show that the predicted change in flood hazard over the Kelantan River Basin is large and regionally diverse based on each scenario. The current HEC-RAS model's capacity to estimates on unsteady river flow has demonstrated to be effective in simulating flood events, which is critical because flood events like during the 2014 are projected to occur more frequently in the future. Furthermore, flood extent projections are also generated and displayed that Pasir Puteh, Bachok, and Kota Bharu may face larger flooding risks in the future. These events demonstrate that Kelantan River Basin is highly vulnerable to flood risk and requires mitigation measures such as the flood hazard projection. In developing flood projection for the future, the present study only considering the rainfall changes at Kelantan River Basin. Tidal effects may be deemed appropriate to be included. This is because the Kelantan River Basin was strongly influenced by tidal conditions based on previous flood events. Tide height is influenced by both short-term meteorological impacts brought on by severe weather and long-term astronomical influences, which are mostly driven by the moon and sun. Therefore, projections of future flood projection by considering the tidal effects will give more accurate depictions of future hydrological response at Kelantan River Basin.

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