The effects of climate change on flood hazards in Kelantan River Basin Malaysia

Tze Huey Tam¹, Muhammad Zulkarnain Abd Rahman¹*, Sobri Harun², Sophal Try³, Ismaila Usman Kaoje¹, Mohd Radhie Mohd Salleh¹, and Kimberly Vivian Abai¹

¹TropicalMap Research Group, Faculty of Built Environment and Surveying, Universiti Teknologi Malaysia, 81310 UTM, Johor Bahru, Johor, Malaysia
² Department of Hydraulic and Hydrology, Universiti Teknologi Malaysia, 81310 UTM, Johor Bahru, Johor, Malaysia
³ Disaster Prevention Research Institute, Kyoto University, Japan.

*Corresponding E-mail: mdzulkarnain@utm.my

Abstract. Climate change has had a significant impact on the hydrological cycle, causing changes in precipitation patterns in both frequency and magnitude. The aim of this study is to assess the effect of climate change on flood hazards in Kelantan River Basin, Malaysia. A distributed hydrological model called Rainfall-Runoff-Inundation (RRI) simulates floods under current and future climate scenarios. The Climate Change Factor (CCF) is a tool for forecasting future climate scenarios. The storm used in this analysis had 50-year and 100-year recurrence intervals every 24 hours (ARI). The finding shows that the streamflow in Guillemard station will increase in the future for both the 50- and 100-year ARI. The streamflow increased to 10329 m³/s from 8434.9 m³/s in the current state and to 11220.2 m³/s from 9157.4 m³/s in the 50- and 100-year ARI, respectively. In both cases, the 100-year ARI flood magnitude is significantly less than the 50-year ARI flood extent (current and future). However, the flood depth in several towns located downstream of the Kelantan River Basin is more significant for the 100-year ARI than for the 50-year ARI for both cases. The study's findings would be helpful to relevant agencies and government departments understand the current and potential flood hazard situation in the study area and assist them in developing effective mitigation strategies for future flood hazards.

Keywords: Climate Change, Flood Hazard, RRI, Kelantan River Basin, Climate Change Factor

Track Name: Land, Water, Forests and Food Security

1. Introduction

Human activities have had a significant impact on the Earth's energy budget by releasing anthropogenic greenhouse gases such as carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O) into the atmosphere over the last few centuries. As a consequence, the global mean surface air
temperatures over land and oceans increased. From 1880 to 2012, the global averaged combined land and ocean surface temperature increased by 0.85 [0.65 to 1.06]°C [1]. The Intergovernmental Panel on Climate Change (IPCC) AR5 report, on the other hand, reported an increase in global average temperature from 1.0° C in the lowest emission scenario to 3.7° C in the highest emission scenario by 2100 [2]. As a result, changing precipitation or melting snow and ice are altering hydrological systems in many regions [1]. Dore [3] examined global precipitation patterns using observed data and concluded that climate change is causing increased variability in precipitation across the globe, with wet and dry areas becoming wetter and drier, respectively. His findings also revealed increased precipitation in high latitudes (Northern Hemisphere), decreased precipitation in China, Australia, a small Pacific island, and increased variability in equatorial regions. Also, there is likely increase in extreme precipitation under a future climate in some areas in Europe [4], in Southeast Asia [5, 6], and in central America [7]. Tabari [8] analysed the relationship of future changes in extreme precipitation and flood events with water availability. The results showed that an intensification of extreme precipitation and flood events over all climate regions which increases as water availability increase from wet to dry regions. Also, there is an increase in the intensification of extreme precipitation and flood with the seasonal cycle of water availability.

Several studies have found an increasing precipitation trend in Malaysia [9-12], which has increased the number of extreme events in 21st century, particularly floods [9]. In Malaysia, floods are generally classified into two types: flash flood and monsoon flood [13]. The latter occurs almost every year and has a severe impact along east coast of Peninsular Malaysia (the affected states included Kelantan, Terengganu, Pahang). Furthermore, Tan et al. [11] concluded that the monthly precipitation in Kelantan River Basin increases during the wet season. As a result, it is possible to predict where more floods will occur in the future. To date, only a few studies on flood hazard in Malaysia under climate change condition have been published [14, 15].

General Circulation Models (GCMs) are used to project future climatic variables to predict the likelihood of increased flood risk from global warming [16]. Various studied used GCMs model have been conducted in Malaysia. For example, [17] and [18] identified the best GCM models to conduct climate change study in Malaysia. [11, 19, 20] assessed the effects of climate change on streamflow in different basins. [10] examined the future precipitation patterns under different climate scenarios. However, only limited studies used Climate Change Factor (CCF) for projecting flood hazard [15]. CCF is define as a ratio of the design rainfall for the future period to the control period [21].

The main objective of this study to assess the effects of climate change on flood hazard in Kelantan River Basin under 50-year and 100-year return period using CCF and the Rainfall-Runoff-Inundation (RRI) model.

2. Material and Methods

2.1. Study Area

In Malaysia, the Kelantan River Basin is the most vulnerable to flooding. In December 2014, a most disastrous flood occurred, resulting in an estimated loss of 2.8 billion ringgit (685 million USD) with 151,072 victims, and ten deaths [22]. [23] conducted a flood hazard assessment for this extreme event in the Kelantan River Basin downstream. According to the findings, Tanah Merah had the highest flood depth of 5.9 m among the affected towns, followed by Pasir Mas, which had 3 m depth.

Figure 1 shows the study area. The Kelantan River Basin is located between 101.4° E and 102.7° E, and 4.6° N and 6.0° N, with an elevation range of 2 to 2174 m. The catchment area of the basin is about 13031.6 km². During the Northeast and Southwest Monsoons, the basin receives about 1530 mm year⁻¹ and 993 mm year⁻¹, respectively [24].
2.2. **RRI model**

The RRI is a 2D fully distributed hydrological model that simulates rainfall-runoff and flood level simultaneously (Figure 2) [25]. At a pixel is river channel, this model presumes slope and river are at same pixel cell. 2D and 1D diffusive equations are used to calculate the flow on the slope pixel and the flow in a channel, respectively. This model simulates lateral subsurface flow, vertical infiltration flow and surface flow for describing the processes of rainfall-runoff-inundation. The lateral subsurface flow consists of saturated subsurface and surface flow. The Green-Ampt equation is responsible for vertical infiltration flow. The flow interaction of river channel and land is estimated based on different overflowing formula. The RRI model is a standalone product and its output, i.e., discharge, water level, and inundation can be displayed easily. In addition, the maximum flood inundation can be saved into ASCII format for further analysis, such as flood hazard mapping or identification of elements-at-risk, using with GIS platform additional data.

This study used the same model parameters as the previous paper [22] to simulate flood. They used various Near-Real-Time (NRT) Satellite Rainfall Products (SRPs) to simulate an extreme flood event in December 2014.

2.3. **Design Storm**

The Intensity Duration Frequency (IDF) of every rain gauge station were used to calculate the 24-hr design rainfall intensity. The empirical IDF equation is written in Equation 1.

\[ i = \frac{\lambda T^k}{(d + \theta)^\eta} \]

where,

- \( i \) = average rainfall intensity (mm/hr),
- \( T \) = return period,
- \( d \) = storm duration

The value of these parameters (i.e., \( \lambda \), \( k \), \( \theta \), and \( \eta \)) of every stations can refer to [21].

Once the design rainfall intensity is calculated, the future design rainfall intensity can be obtained by multiply with the coefficient of climate change factor (CCF). One can refer to [21] to gain more
information about the CCF. Table 1 show the 50-year and 100-year rainfall depth of every station for current and future scenarios.

![Figure 2. Schematic diagram of Rainfall-Runoff-Inundation (RRI) Model.](image)

**Table 1.** Future and current 24-hour rainfall depth of 50-year and 100-year

| Station            | Current 50 ARI | Future 50 ARI | Current 100 ARI | Future 100 ARI | Increase 50 ARI | Increase 100 ARI |
|--------------------|----------------|---------------|-----------------|----------------|----------------|------------------|
| Balai Polis Bertam| 214.4          | 240.9         | 293.7           | 337.2          | 37 %           | 40 %             |
| Dabong             | 270.2          | 308.0         | 424.2           | 495.9          | 57 %           | 61 %             |
| Brook              | 175.9          | 196.4         | 255.1           | 294.6          | 45 %           | 50 %             |
| Gob                | 201.0          | 226.9         | 259.3           | 297.3          | 29 %           | 31 %             |
| Gua Musang         | 200.2          | 222.9         | 238.2           | 269.7          | 19 %           | 21 %             |
| Kuala Krai         | 392.7          | 460.9         | 518.4           | 617.6          | 32 %           | 34 %             |
| Machang            | 405.4          | 471.9         | 559.5           | 665.4          | 38 %           | 41 %             |
| Aring              | 313.5          | 356.9         | 417.0           | 485.4          | 33 %           | 36 %             |
| Jeli               | 395.1          | 452.6         | 525.5           | 615.6          | 33 %           | 36 %             |
| Lalok              | 295.7          | 338.9         | 375.5           | 437.2          | 27 %           | 29 %             |

3. **Results and Analysis**

3.1. **Future rainfall depth changes**

Table 1 depicts the 24-hour rainfall depth in current and future scenarios for 50-year and 100-year return periods. With a margin of at least 20 %, future rainfall depth exceeds current rainfall depth. Furthermore, for 50-year and 100-year return periods, the range increased from 19 % to 57 % and from 21 % to 61 %, respectively. Dabong and Gua Musang experienced the most remarkable and least significant percentage increases, respectively. Machang had the greatest rainfall depth of the stations, with 665.4 mm in the future and 471.9 mm in the current 100-year return period. On the other hand, Brook had the lowest rainfall depth in both the current and future scenarios, at 196.4 mm and 294.6 mm, respectively. The increased depth of rainfall implies that the future flood hazard in the Kelantan River Basin will worsen.
3.2. *Impact of climate change on peak discharge*

Figure 3 depicts the peak discharge for the 50-year and 100-year return periods in the current and future scenarios. The simulated streamflow collected based on Guillemard station. The 50-year peak discharge increased to 10,329 m$^3$ s$^{-1}$ from 8,434.9 m$^3$ s$^{-1}$. At the same time, the 100-year peak discharge increased to 11,220.2 m$^3$ s$^{-1}$ from 9,157.4 m$^3$ s$^{-1}$. The increase of peak discharge in the future is expected since the future rainfall depth increased too. These findings are consistent with the climate change impacts on water resources reported by [11].

![Figure 3: Comparison of current and future peak discharge for 50-year and 100-year.](image)

3.3. *Impact of climate change on flood depth*

Figure 4 shows the current and projected flood depth in the affected towns downstream of the Kelantan River Basin. Overall, flood depths are expected to rise in the future for 50-year and 100-year. Tanah Merah had the significant flood depth among the towns, followed by Pasir Mas, Kadok, and Wakaf Baru. The rest of the towns, however, had similar flood depths. Tanah Merah had a projected flood depth of 3.85 m in a 100-years event, followed by Pasir Mas at 2.09 m, Kadok at 1.43 m and Wakaf Baru at 1.14 m. The remaining towns have a flood depth of less than 1 m. However, the highest 100-year flood depth in Tanah Merah in the future is less than the flood event in December 2014, as illustrated in Figure 4. The only explanation is that the digital elevation model (DEM) used in this study has a coarser spatial resolution of 0.9 km.
3.4. Impact of climate change on flood hazard

Figure 5 depicts the 50-year and 100-year flood hazard in the Kelantan River Basin downstream. The flood hazard classification is based on flood depth adopted from a previous study [26]. As shown in Figure 5, the flood hazard in the future appears to be increased compared to the current scenario, particularly in Tanah Merah. Furthermore, there are noticeable changes in the hazard level on the east and northwest sides of the basin. As a result, the total inundated area increased in the future. Table 2 displays detailed flood hazard information for each town. According to Table 2, only Tanah Merah will have a high level of flood hazard in the future, up from the current moderate level. In the current and future scenarios, the rest of the towns had levels that were moderate or lower than moderate.
Figure 5. Flood Hazard in downstream of Kelantan River Basin.

Table 2. Degree of future and current flood hazard in the affected towns.

| Town     | 50-year Current | 50-year Future | 100-year Current | 100-year Future |
|----------|----------------|---------------|------------------|-----------------|
| Tumpat   | Very Low       | Very Low      | Very Low         | Very Low        |
| Wakaf Baru | Low           | Low           | Low              | Moderate        |
| Kota Bharu | Very Low      | Very Low      | Very Low         | Very Low        |
| Pasir Mas  | Moderate      | Moderate      | Moderate         | Moderate        |
| Kadok     | Low           | Moderate      | Low              | Moderate        |
| Peringat  | Very Low       | Very Low      | Very Low         | Very Low        |
| Tanah Merah | Moderate     | High          | Moderate         | High            |
4. Conclusion

The effects of climate change on flood hazard in the Kelantan River Basin were discussed in this paper. The climate change factor (CCF) was used to forecast future rainfall depth over 50 and 100 years. The rainfall depth was used to drive the RRI model, which generated flood simulations and assessed flood hazards under various scenarios. According to the findings of this study, climate change poses a significant risk to the Kelantan River Basin. As a result, river basin management that seeks to reduce the risk of flooding must consider the impact of future climate change.

References

[1] IPCC 2014 Climate Change Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC, Geneva, Switzerland

[2] IPCC 2018 Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty

[3] Dore M H I 2005 Climate change and changes in global precipitation patterns: What do we know? Environment International 31 (8) 1167-81.

[4] Madsen H et al 2014 Review of trend analysis and climate change projections of extreme precipitation and floods in Europe Journal of Hydrology 519 (PD) 3634-50

[5] Tangang F et al 2018 Future changes in annual precipitation extremes over Southeast Asia under global warming of 2 C APN Science Bulletin 6 (1)

[6] Raghavan S N et al 2018 Evaluations of NASA NEX-GDPP data over Southeast Asia: present and future climates Climatic Change 148 (4) 503-18.

[7] Imbach P et al 2018 Future climate change scenarios in Central America at high spatial resolution PLOS ONE 13 (4) e0193570.

[8] Tabari H 2020 Climate change impact on flood and extreme precipitation increases with water availability Scientific Reports 10 (1)

[9] Tang K H D 2019 Climate change in Malaysia: Trends, contributors, impacts, mitigation and adaptations Science of The Total Environment 650 1858-71

[10] Hussain M et al 2017 Projected changes in temperature and precipitation in Sarawak state of Malaysia for selected CMIP5 climate scenarios International Journal of Sustainable Development and Planning 12 (8) 1299-311

[11] Tan M L et al 2017 Climate change impacts under CMIP5 RCP scenarios on water resources of the Kelantan River Basin, Malaysia Atmospheric Research 189:1-10

[12] Amin I M Z b M et al 2019 Impacts of Climate Change on the Hydro-Climate of Peninsular Malaysia Water 11 (9) 1798

[13] DID 2009 Volume 1 – Flood Management.

[14] Aziz N A A et al 2016, editors. Effect of Climate Change to Flood Inundation Areas in Bertam Catchment, Pahang Springer Singapore

[15] Winarta B et al 2019 editors. Flood Inundation Assessment under Climate Change Scenarios in Kuantan River Basin, Malaysia IOP Conference Series: Earth and Environmental Science

[16] Mishra B K et al 2018 Assessment of future flood inundations under climate and land use change scenarios in the Ciliwung River Basin, Jakarta. Journal of Flood Risk Management 11 S1105-S15.

[17] Salman S A et al 2020 Selection of CMIP5 general circulation model outputs of precipitation for peninsular Malaysia Hydrology Research 51 (4) 781-98

[18] Noor M et al 2019 Selection of CMIP5 multi-model ensemble for the projection of spatial and temporal variability of rainfall in peninsular Malaysia Theoretical and Applied Climatology 138 (1) 999-1012.

[19] Ismail H et al 2020 Assessment of climate change impact on future streamflow at Bernam river basin Malaysia IOP Conference Series: Earth and Environmental Science

[20] Adib M N M et al 2020 Projected Streamflow in the Kura River Basin of Western Malaysia under Future Climate Scenarios Scientific Reports 10 (1) 8336

[21] NAHRIM 2013 Technical Guide: Estimation of Future Design Rainstorm under the Climate Change Scenario in Peninsular Malaysia

[22] Yahaya N S et al 2015 The December 2014 flood in Kelantan: A post-event perspective

[23] Tam T H et al 2019 Application of Satellite Rainfall Products for Flood Inundation Modelling in Kelantan River Basin, Malaysia Hydrology 6 (4) 95.

[24] Wong C L et al 2016 Rainfall characteristics and regionalization in Peninsular Malaysia based on a high resolution gridded data set Water 8 (11) 500.

[25] Sayama T et al 2012 Rainfall–runoff–inundation analysis of the 2010 Pakistan flood in the Kabul River basin Hydrological Sciences Journal 57 (2) 298-312

[26] Usman Kaoje I et al 2020 Physical flood vulnerability assessment of buildings in Kota Bharu, Malaysia: an indicator based approach International Journal of Disaster Resilience in the Built Environment
Acknowledgments

The authors would like to express their gratitude to the Institut Penyelidikan Air Kebangsaan Malaysia (NAHRIM) for providing the hydrological data used in this study. Takahiro Sayama deserves special recognition for developing the RRI model as a public domain model. Finally, the authors would like to express their gratitude to Universiti Teknologi Malaysia (UTM) for financial support under grant GUP Q.J130000.3852.19J74.