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

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

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**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 $m^3/s$ from 8434.9 $m^3/s$ in the current state and to 11220.2 $m^3/s$ from 9157.4 $m^3/s$ 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 ($CO_2$), methane ($CH_4$), and nitrous oxide ($N_2O$) 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 21$^{st}$ century, particularly floods [9]. In Malaysia, floods are generally classified into two types: flash flood and monsoon flood [13]. The latter occurrs 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 km$^2$. During the Northeast and Southwest Monsoons, the basin receives about 1530 mm year$^{-1}$ and 993 mm year$^{-1}$, respectively [24].

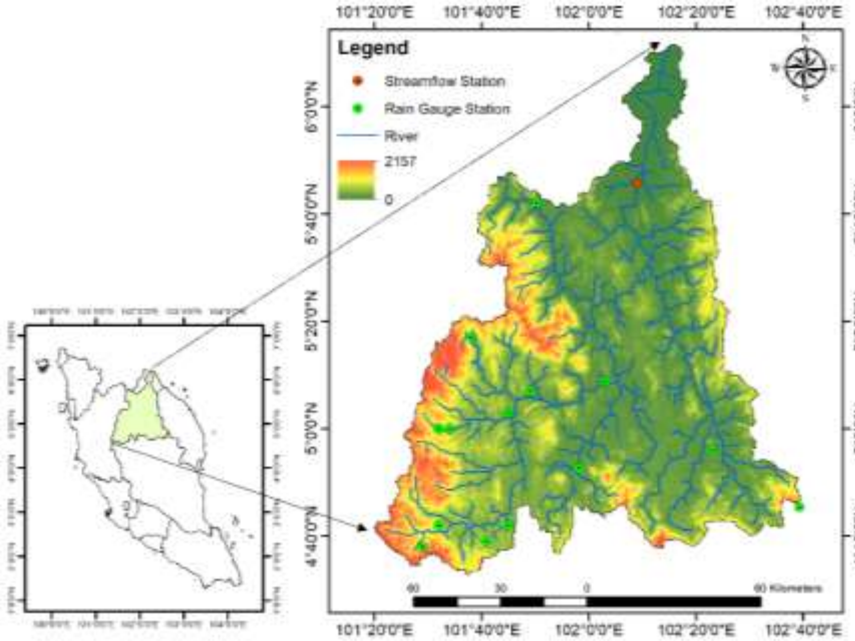


**Figure 1.** Kelantan River Basin.

### 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.

$$i = \frac{\lambda T^k}{(d+\theta)^\eta} \tag{1}$$

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

The value of these parameters (i.e., λ, k, θ, and η) 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.

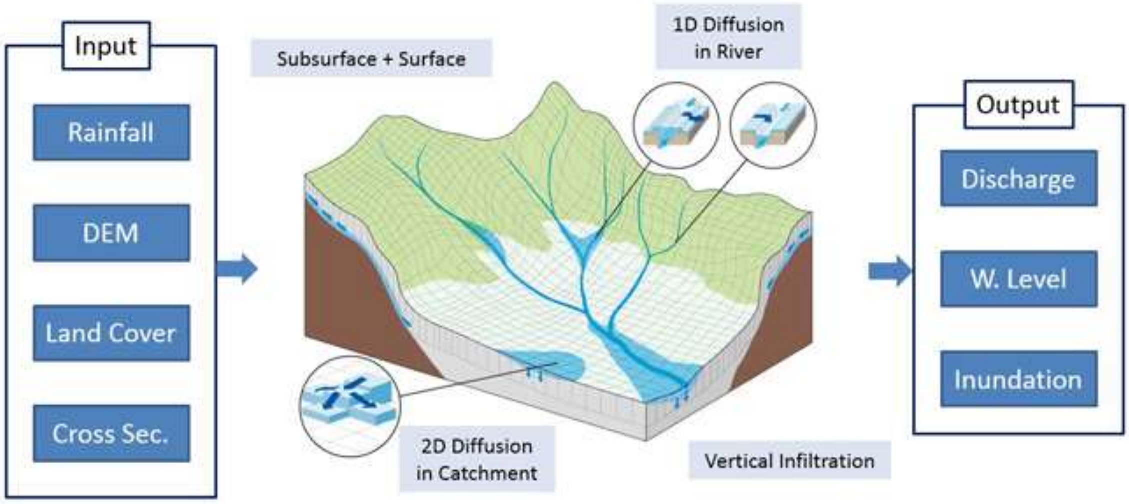


**Figure 2.** Schematic diagram of Rainfall-Runoff-Inundation (RRI) Model.

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

| | Current | | Future | | Increase | |
|---|---|---|---|---|---|---|
| | 50 ARI | 100 ARI | 50 ARI | 100 ARI | 50 ARI | 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].

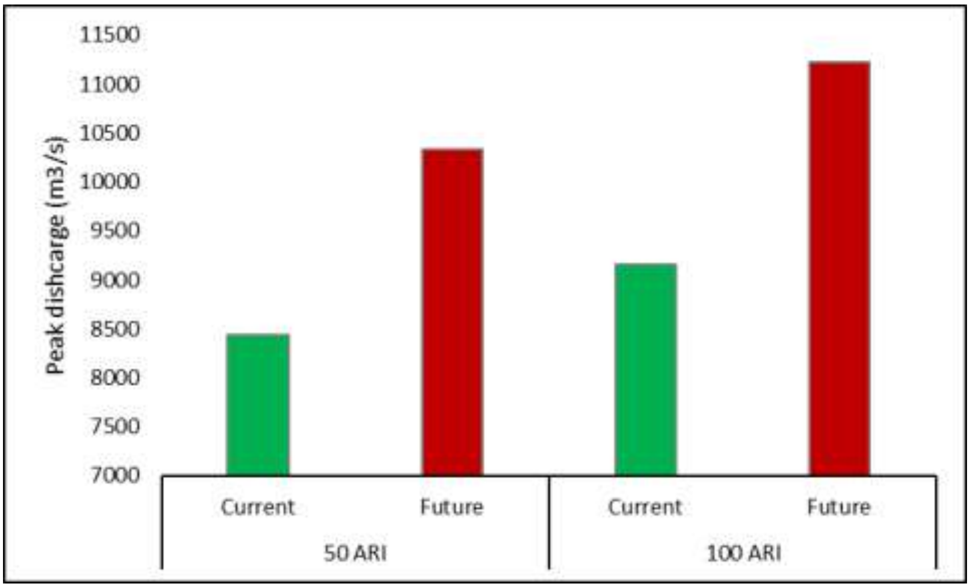


**Figure 3.** Comparison of current and future peak discharge for 50-year and 100-year.

### *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.

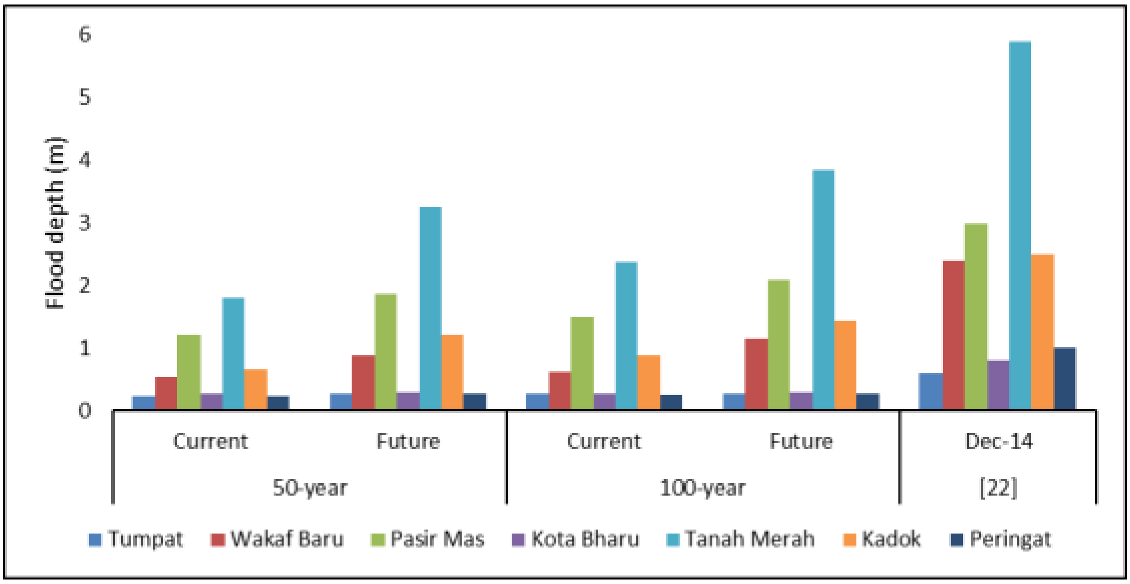


**Figure 4.** Current and future flood depth.

*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.

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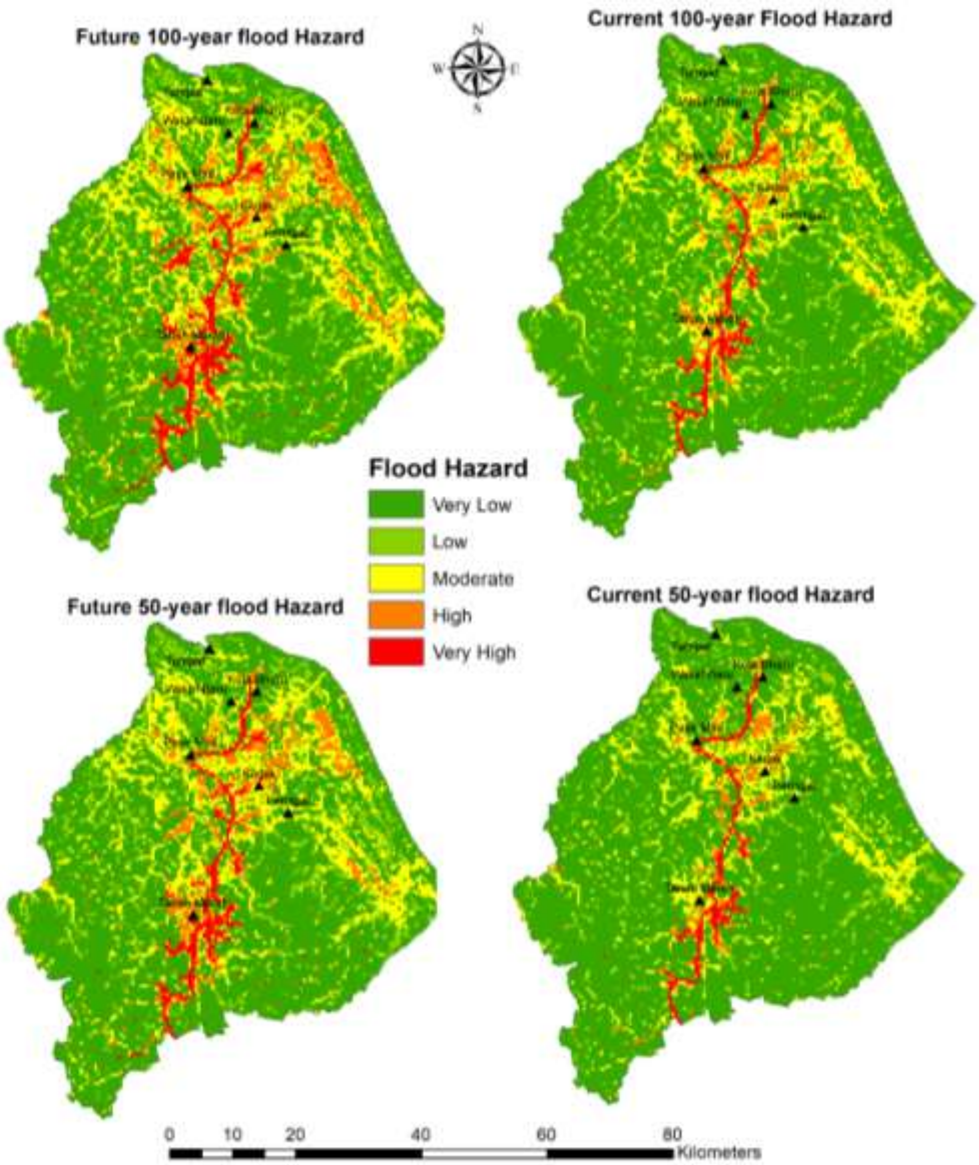


**Figure 5.** Flood Hazard in downstream of Kelantan River Basin.

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

| | 50-year | | 100-year | |
|---|---|---|---|---|
| | Current | Future | Current | 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.

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