Flood Hazard Assessment Under Climate Change Scenarios in Kelantan River Basin, Malaysia

Tze Huey Tam (✉ thtam2@live.utm.my)

Universiti Teknologi Malaysia <https://orcid.org/0000-0002-3493-0711>

Muhammad Zulkamain Abdul Rahman

Universiti Teknologi Malaysia

Sobri Harun

Universiti Teknologi Malaysia

Sopha Try

Kyoto University - Uji Campus: Kyoto Daigaku - Uji Campus

Shamsuddin Shahid

Universiti Teknologi Malaysia

Mohamad Hidayat Jamal

Universiti Teknologi Malaysia

Zamri Ismail

Universiti Teknologi Malaysia

Khamarrul Azahari Razak

Universiti Teknologi Malaysia

Mohd Khairolden Ghani

Construction Industry Development Board Malaysia

Yusrin Faiz Abdul Wahab

CREAM: Construction Research Institute of Malaysia

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Abstract

Climate change can significantly alter the hydrological cycle and lead to severe hydrological disasters. This study aims to determine the impact of climate change on flood hazards in the Kelantan River Basin of Malaysia. The Climate Change Factor (CCF) is used to calculate 24-hour design rainfall with 50, 100 and 200-year return periods. A distributed hydrological model, Rainfall-Runoff-Inundation (RRI), is used to simulate flood inundation under current and future climate scenarios. The results indicate an increase in 50, 100, and 200 years, design rainfall, streamflow and flood hazard. The expected design rainfall and streamflow for 50, 100, and 200 years would increase by 36.6%, 37.9%, 42.7%, and 43.2%, 32.7%, 36.5%, respectively. Flood hazard is spatially variable in the Kelantan River Basin. Tanah Merah is the town that would face a significant increase in future flooding. The findings of this study can aid relevant agencies and government departments to comprehend the current and future flood hazard situation in the Kelantan River Basin. It would also assist them in formulating appropriate flood management strategies to mitigate future severe flood hazards.

1 Introduction

Floods are the most frequently occurring natural disaster in Malaysia, especially during the Northeast Monsoon (November to January), when heavy rainfall occurs along the east coast of Peninsular Malaysia (Tang, 2019). Human activities have increased global temperature since the mid-20th century, altered precipitation patterns and hydrological systems (IPCC, 2014). Several studies have been conducted to assess the changes in rainfall patterns in Malaysia (Wan Zin et al., 2009, Tangang et al., 2012, Wong et al., 2009, Nashwan et al., 2019). These studies found an increase in mean precipitation and its intensity during the Northeast monsoon. This indicates more floods due to climate change, confirming the phrase "there is no such thing as a natural disaster". The recent unprecedented flood in the Kelantan River Basin in December 2014 could be attributed to climate change effects. This extreme event affected 151,072 people, yielded approximately 2.8 billion losses in the economy, and resulted in 10 deaths (Yahaya et al., 2015).

There have been numerous studies focusing on assessing the climate change impacts on flood hazards around the world. Dankers and Feyen (2008) and Shrestha and Lohpaisankrit (2017) found that the projected flood frequency in Europe and Thailand will increase to 25-year from 100-year flood. Dobler et al. (2012) reported that the projected mean annual floods in the Lech Basin decreased by 15%, the timing of the annual maximum flood increased dramatically from 7 months under current conditions to 12 months in the future scenarios. Also, summer and winter floods will be decreased by around 25% and increase by 50%, respectively. Dutta and Ghosh (2012) shown that the in Brahmaputra Basin, flood duration will increase from 15.2 days to 19.3 days, and peak flow will increase by 21%. According to Robi et al. (2019) and Mishra et al. (2018), the projected inundation area and depth in Nile River Basin and Ciliwung River Basin, respectively, would increase. Nevertheless, none of these studies has focused on the effects of climate change on design storms-included flood hazards.

Climate simulations by Global Climate Model (GCM) or Regional Climate Model (RCM) are generally used to assess the possible climate change. RCM provides improved resolution and better representation of the topography and various land-surface conditions (Amin et al., 2016). Several studies have been conducted using GCM or RCM to examine the impact of climate change on hydrology and water resources in Malaysia (Tan et al., 2017, Shaaban et al., 2011, Mohd et al., 2015). The findings of these studies revealed an increase in rainfall in the wet season (November to January) along the east coast of Peninsular Malaysia. As a result, there might be more frequent extreme flood events in this region in the future.

Kelantan River Basin is the most flood susceptible river basin in Peninsular Malaysia during the northeast monsoon season. However, the development of a flood hazard map in the basin is still incomplete. Flood maps of only two sub-basins of Kelantan River have been prepared so far, including Pasir Mas and Tanah Merah flood hazard maps of 2010 (Zakaria et al., 2017). Besides, only limited studies aimed to investigate flood regime changes in Malaysian river basins due to climate change (Winarta et al., 2019, Aziz et al., 2016). None of the studies focuses on Kelantan River Basin. However, the generation of a flood hazard map in the Kelantan River Basin for the current and future scenarios is crucial to support flood risk management of the basin.

Structural measures (such as dams, dikes, retention ponds, flood protection walls) are employed to mitigate flood hazards. It is essential to have a thorough understanding of the flood hazard for planning structural measures for flood mitigation. Climate Change Factor (CCF) is a technical tool used to address the impact of climate change on design floods (Pelaez Jara, 2020). It is required to incorporate in the estimated design rainstorm and rainfall intensity to aid flood mitigation planning (DID, 2018).

The main objective of this study is to evaluate the projected change in flood hazards in the Kelantan River Basin due to climate change. The notable aspects of this study are: (1) to determine 24-hour rainfall under 50-year, 100-year, and 200-year annual recurrence interval (ARI) flood hazard in current and future scenarios, and (2) to investigate the effect of flood hazard in the Kelantan River Basin in current and future scenarios.

2 Methods And Materials

2.1 Study area

Figure 1 shows the location of the study area. The Kelantan River Basin, located between 101.4 E° and 102.7° E, and 4.6° N and 6.0° N, covers a catchment area of approximately 13,031 km². The elevation of the basin ranges from 2 to 2,174 m. The basin receives about 1,530 mm/year precipitation during the Northeast and 993 mm/year during the Southwest Monsoons (Wong et al., 2016). Table 1 illustrated the major flood events in the Kelantan River Basin. We summarized this information using historical water level data in the Guillermand station provided by the Department of Irrigation and Drainage (DID). The

station location is shown in Fig. 1. The most severe flood event in the basin occurred in December 2014, when the water depth in Guillerpard station hit 6.8 m, above the river danger limit.

Table 1
Flood events occurred in Kelantan River Basin. The highlighted record indicates a severe flood event.

Flood event	Flood depth (m)
Nov 2001	1.9
Dec 2003	1.9
Dec 2004	4.6
Nov 2005	0.8
Dec 2005	1.0
Feb 2006	0.6
Jan 2007	0.3
Dec 2007	2.8
Nov 2008	0.9
Jan 2009	1.6
Nov 2009	2.7
Nov 2011	0.2
Jan 2012	0.3
Dec 2012	0.6
Feb 2013	2.0
Dec 2013	1.2
Dec 2014	6.8

2.1 Rainfall-Runoff-Inundation (RRI) Model

The RRI is a 2D fully distributed hydrological model that simultaneously simulates rainfall-runoff and flood level (Fig. 2) (Sayama et al., 2012). At a river channel, this model presumes slope and river are at the same pixel cell. The model uses 2D and 1D diffusive equations to calculate the flow on the slope pixel and the flow in a channel, correspondingly. 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 represents

the vertical infiltration flow. The flow interaction with river channels and land is estimated based on the different overflowing formulas. 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 GIS platform.

2.2 Data sources

2.2.1 Cross-section

The Department of Irrigation Drainage (DID), Malaysia provides a total of five cross-section for Kelantan River and its main tributaries, as shown in Fig. 1. This data was collected in 2013. One can refer to Tam et al. (2019) for getting the river geometry parameters value.

2.2.2 Digital Elevation Model (DEM)

The USGS HydroSHED topographic data was used in this study (Lehner et al., 2008), as it is a hydrologically conditioned topographic data. Therefore, this data is suitable for hydrological applications. This study used topographic data of digital elevation model (DEM), flow direction and flow accumulation from HydroSHED with a spatial resolution of 15 arcsec (approximately 450 m at the equator).

2.2.3 Land cover and soil map

The Global Land Cover data of the National Mapping Organizations (GLCNMO) was used in this study. It is developed from Moderate Resolution Imaging Spectroradiometer (MODIS) remote sensing data (Tateishi et al., 2014). The GLCNMO version 2, having a spatial resolution of 15 arcsec, was used. Soil data of the Food and Agriculture Organization (FAO) of the United Nation's global dataset with approximately 9 km resolution (IIASA/FAO, 2012) was used.

2.2.4 Design Storm

The Intensity Duration Frequency (IDF) was used to calculate the 24-hr design rainfall intensity. The empirical IDF equation is as below,

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

1

where,

i = average rainfall intensity (mm/hr),

T = return period,

d = storm duration

The parameters λ , k , θ , and η , prescribed by NAHRIM (2013) for each station, were used.

After calculating the design rainfall intensity, the future design rainfall intensity was estimated by multiplying the current design rainfall intensity with the coefficient of climate change (CCF). One can refer to nahrim (2013) for more information about the CCF. Nevertheless, the CCF is derived from 18 GCMs. The Special Report on Emissions Scenarios (SRES) A1B scenario was used to drive the simulation of the 18 GCMs. This dataset covers two time periods: 1981–2000 for the current climate and 2046–2065 for the future scenario. The estimated rainfall depths for 50 and 100-year ARI at each station for current and future scenarios are presented in Table 2.

Table 2
The 24-hour rainfall depths of 50-year and 100-year in current and future scenarios.

	Current (mm)		Future (mm)		Increase (mm)	
	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%

2.3 Temporal Pattern

The temporal distribution of the recorded storms is commonly used to determine the temporal distribution of design storms or the distribution of rainfall depth for a storm duration. The temporal distribution of rainfall is an important feature in rainfall-runoff modelling. The design temporal pattern can have a considerable impact on the design flood. 24-hour temporal rainfall distribution, designed for Kelantan, was used in this study. More information on temporal rainfall distribution can be found in (NAHRIM, 2010).

2.4 Model Calibration

The RRI model needs to be calibrated before it is used for design rainfall simulation. Table 3 illustrates the optimum parameter values of RRI model to simulate design rainfall simulation. The values were estimated for the December 2014 flood event in Kelantan River Basin using satellite rainfall products by Tam et al. (2019). The main reason for using this set of parameters is that simulating design rainfall is akin to simulating an extreme flood event.

Table 3
The Rainfall-Runoff-Inundation (RRI) model's parameters with their optimal values.

Parameters	Recommended ranges	Optimized value
n (River)	0.015–0.040	0.04
n (Land)	0.150–1.000	1.00
Soil depth (m)	0.500–2.000	2.00
Porosity (gamma)	0.300–0.500	0.30
ka (m/s)	0.010–0.300	0.20

Table 4
Flood hazard classification.

[Modified from Usman Kaoje et al. (2021)]

Flood depth	Hazard
< 0.5 m	Very Low
0.5–1 m	Low
1–3 m	Moderate
3–5 m	High
< 5 m	Very High

2.5 Classification of hazard

The flood hazard classification is based solely on flood depth, as depth considered by the stage-damage curve is the primary flood characteristic used to estimate the potential of flood damage (Jongman et al., 2012, de Moel and Aerts, 2011).

3 Results And Discussion

3.1 Analysis of basin rainfall depth

Figure 3 shows the comparison of 50-year, 100-year, and 200-year return period rainfall depth in the basin for the current and future scenarios. In general, the trend in rainfall depth for 200-year return period and

future scenario is more significant than in the 50-year and 100-year return periods and current scenario. The results showed that the peak of 50-year, 100-year, and 200-year return period rainfall depths increased by 36.6%, 37.9%, and 42.7%, respectively, in the future scenario compared to the current scenario. The projected 50-year, 100-year, and 200-year return period rainfall depths were 26.5 mm/hr, 30.9 mm/hr, and 36.4 mm/hr, while the current 50-year, 100-year, and 200-year return period rainfall depths were 19.4 mm/hr, 22.4 mm/hr, and 25.5 mm/hr, respectively. For the current scenario, the finding of this study is consistent with the results obtained by Nashwan et al. (2019) through a nonstationary analysis of extreme rainfall in Peninsular Malaysia.

Overall, the basin rainfall depth for different return periods indicates an increasing trend, particularly for the future scenario. The CCF for each station was greater for longer return periods than for short and medium return periods. However, few recent studies reported an increasing trend in the future rainfall intensity in the Kelantan River Basin for short and medium return periods (e.g., 2-year, 5-year, 10-year, and 25-year), for most stations having CCF greater than 1 and return periods of 50-year and 100-year having CCF less than 1 (Shukor et al., 2020, Noor et al., 2018). Based on these findings, it can be remarked that the effect of climate change on future rainfall patterns in the Kelantan River Basin is inconsistent. As a result, it is essential to update the Intensity-Duration-Frequency curve regularly and calculate the CCF to obtain more accurate forecasts of future rainfall affected by climate change and derive reliable hazard information.

3.2 Impact of climate change on peak discharge

Figure 4 illustrated the simulated runoff for 50-year, 100-year, and 200-year return periods for the present and future scenarios. The hydrographs were simulated at the Guillermand station (Fig. 1). The pattern of simulated runoff was similar to that of design rainfall. The simulated runoff for the 200-year return period and the future scenario was much higher than the ones for 50-year and 100-year return period and the current scenario. The peak of the 50-year, 100-year, and 200-year return period simulated streamflow showed an increase by 43.2, 32.7, and 36.5%, respectively, for the future scenario compared to the current scenario. The projected 50-year, 100-year and 200-year peak runoff were 8,446.6, 9,445.4, and 10,380.7 m³/s, respectively. In contrast, the current 50-year, 100-year, and 200-year simulated runoff were 5,896.9, 7,116.9, and 7,606.1 m³/s, respectively. Additionally, Fig. 4 demonstrates that increasing rainfall results in increased runoff. This finding is consistent with the studies of Adnan (2015) and Tan et al. (2017). The results indicate a direct relationship between rainfall and runoff in the Kelantan River Basin.

Model calibration is the most important procedure in hydrological modelling for optimizing model performance (Gupta et al., 1998). A model can be calibrated manually or automatically. Nevertheless, numerous studies have demonstrated that automatic calibration produces good agreement between simulated and measured streamflow than manual calibration (Li et al., 2012, Kim et al., 2007, Seong et al., 2015, Bouda et al., 2014). The parameter values for the RRI employed in this investigation were derived from previous work (Tam et al., 2019), although manual calibration was used to reach the optimal

parameter value. In this case, it is assumed that the calibrated set of parameters may impact the current simulation result.

3.3 Impact of Climate Change on flood hazard

Figure 5 depicts the flood depths in towns located in the Kelantan River's downstream. The results showed an increase in 50-year, 100-year, and 200-year return period flood depth. Tanah Merah would experience the highest flood depth among the towns, followed by Pasir Mas, Kadok, and Wakaf Baru. The remaining towns, on the other hand, would experience similar flood depths. The projected flood depth in Tanah Merah for a 200-year return period flood event was 4.59 metres followed by Pasir Mas (2.3 metres), Kadok (1.67 metres), and Wakaf Baru (1.63 metres). The 200-year return period flood depth at the remaining towns would be less than one metre.

Table 5 illustrates the level of hazard in affected towns as a function of flood depth. Increasing hazards from the current to the future scenarios are projected higher for Tanah Merah. The hazard for 100-year and 200-year events for Tanah Merah is projected to increase from moderate to high. At the same time, the flood hazard in Wakaf Baru and Kadok is projected to change from low to moderate throughout three return periods. The remaining communities would experience a similar flood risk in the future like the present.

Table 5
Level of future and current flood hazards in the affected towns.

	Current			Future		
TOWN	50-year	100-year	200-year	50-year	100-year	200-year
Tumpat	Very low	Very low	Very low	Very low	Very low	Very low
Wakaf Baru	Low	Low	Low	Moderate	Moderate	Moderate
Kota Bharu	Very low	Very low	Very low	Very low	Very low	Very low
Pasir Mas	Low	Moderate	Moderate	Moderate	Moderate	Moderate
Kadok	Very low	Low	Low	Moderate	Moderate	Moderate
Peringat	Very low	Very low	Very low	Very low	Very low	Low
Tanah Merah	Low	Moderate	Moderate	High	High	High

Figure 6 demonstrates the spatial distribution of flood hazards in the Kelantan River Basin for current and future scenarios. Compared to the present, the extent of flood hazards would be more noticeable along the Kelantan River in the future. Additionally, the flood threat in the vicinity of the estuary indicated that it would become more severe in the future.

This study also assessed the flood hazards associated with various return periods for the Kelantan River Basin for the present and future scenarios. It is considered that the degree of danger is proportional to the

depth of flooding. The study's findings showed that the depth for a 200-year return period flood in the future is still smaller than that of the December 2014 exceptional flood, as illustrated in Fig. 5. The latter was determined by inputting satellite rainfall data into a hydrological model (Tam et al., 2019). One of the possible reasons is that there are insufficient stations in the river basin, which results in a poor representation of the area-based rainfall pattern (Noor et al., 2018). Tam et al. (2019) demonstrated this by comparing several satellite rainfall products and rain gauge data in mapping flood inundation during the December 2014 extreme event. The results showed that the Global Satellite Mapping of Precipitation (GSMaP) product outperformed the rain gauge.

Although the generated flood hazard map may not be reliable, it can be used to update current and future flood hazard information that can be used as input for flood risk assessment to mitigate flood damage. Particularly, it can be used for mitigating floods due to climate change by adopting appropriate risk management strategy.

5 Conclusions

The impact of climate change on flood hazards in the Kelantan River Basin was investigated in this study. The expected rainfall depths in the future for 50-, 100-, and 200-year return periods were estimated using the Climatic Change Factor (CCF) and were utilized to drive the RRI model. Flood hazard maps for 50-, 100-, and 200-year return periods were developed for current and future scenarios. The results revealed an increase in rainfall depths for different return periods in the future compared to the present situation. In addition, there is a direct relation between flood depth with rainfall depth in the Kelantan River Basin. Therefore, a shift in flood depth is expected due to climate change. The study's findings indicate that the expected change of flood hazard is significant and spatially varied across the Kelantan River Basin. The simulation results show that Tanah Merah, Pasir Mas, and Kadok may have a greater risk of flooding in the future than other municipalities. Clearly, this study has contributed to the body of knowledge regarding the effects of climate change on flood inundation, allowing for a better understanding and preparation for climate change adaptation and flood damage reduction methods in the Kelantan River Basin.

Abbreviations

CCF

Climate change factor; RRI:Rainfall-runoff-inundation, GCM:Global Climate Model; RCM:Regional Climate model; ARI:Annual recurrence interval; DID:Department of Irrigation and Drainage; DEM:Digital elevation model; GLCNMO:Global Land Cover data of the National Mapping Organizations; MODIS:Moderate Resolution Imaging Spectroradiometer; FAO:Food and Agriculture Organization; IDF:Intensity Duration Frequency; GSMaP:Global Satellite Mapping of Precipitation

Declarations

Availability of data and material

'Not applicable'

Competing interests

The authors declare that they have no competing interest.

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Authors' contributions

Abdul Rahman M. Z., Jamal M. H., and Ismail Z. proposed the topic and drafted the manuscript. Try S., Ghani M. K. and Abdul Wahab Y. F. helped Tam T. H. in the modelling process. Harun S., Shahid S. and Razak K. A. analyzed and discussed the results. All authors read and approved the final manuscript.

Authors' information

¹ TropicalMap Research Group, Faculty of Built Environmental and Surveying, Universiti Teknologi Malaysia. 81310 Johor, Malaysia ² Department of Water and Environmental Engineering, School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 Johor, Malaysia ³ Disaster Prevention Research Institute, Kyoto University, Kyoto, Japan ⁴ Faculty of Hydrology and Water Resources Engineering, Institute of Technology of Cambodia, Cambodia ⁵ Department of Geoinformation, Faculty of Built Environmental and Surveying, Universiti Teknologi Malaysia. 81310 Johor, Malaysia ⁶ Disaster Preparedness and Prevention Center, Malaysia-Japan International Institute of Technology, Universiti Teknologi Malaysia, Kuala Lumpur 54100, Malaysia ⁷ Construction Research Institute of Malaysia, Construction Research Institute of Malaysia

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Endnotes

References

- Adnan NA (2015) Flooding Changes Analysis Based on Regional Climate Change Scenarios for the Kelantan River Basin. *Malaysian Journal of Remote Sensing GIS* 4:144–154
- Amin MZM, Shaaban AJ, Ohara N, Kavvas ML, Chen AS, Kure S, Jang JH (2016) Climate Change Assessment of Water Resources in Sabah and Sarawak, Malaysia, Based on Dynamically-Downscaled GCM Projections Using a Regional Hydroclimate Model. *J Hydrol Eng*, 21. doi:10.1061/(ASCE)HE.1943-5584.0001242
- Aziz NaA, Malek MA, Jaffar ASM, May R (2016) Effect of Climate Change to Flood Inundation Areas in Bertam Catchment, Pahang. In: Tahir, W., Abu Bakar, P. I. D. S. H., Wahid, M. A., Mohd Nasir, S. R. & Lee, W. K. (ed) ISFRAM 2015. Springer Singapore, Singapore
- Bouda M, Rousseau AN, Gumiere SJ, Gagnon P, Konan B, Moussa R (2014) Implementation of an automatic calibration procedure for HYDROTEL based on prior OAT sensitivity and complementary identifiability analysis. *Hydrol Process* 28:3947–3961. doi:10.1002/hyp.9882
- Dankers R, Feyen L (2008) Climate change impact on flood hazard in Europe: An assessment based on high-resolution climate simulations. *Journal of Geophysical Research Atmospheres*, 113. doi:10.1029/2007JD009719
- De Moel H, Aerts JCJH (2011) Effect of uncertainty in land use, damage models and inundation depth on flood damage estimates. *Nat Hazards* 58:407–425. doi:10.1007/s11069-010-9675-6
- Did (2018) Estimation of Design Rainstorm in Sabah and Sarawak (Revised and Updated 2018)
- Dobler C, Bürger G, Stötter J (2012) Assessment of climate change impacts on flood hazard potential in the Alpine Lech watershed. *J Hydrol* 460–461:29–39. doi:10.1016/j.jhydrol.2012.06.027
- Dutta S, Ghosh S (2012) Impact of climate and land use changes on the flood hazard of the middle Brahmaputra Reach, India. *Journal of Disaster Research* 7:573–581. doi:10.20965/jdr.2012.p0573
- Gupta HV, Sorooshian S, Yapo PO (1998) Toward improved calibration of hydrologic models: Multiple and noncommensurable measures of information. *Water Resour Res* 34:751–763. doi:10.1029/97WR03495
- IIASA/Fao (2012) Global Agro-ecological Zones (GAEZ v3.0)
- Ipcc 2014 Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change
- Jongman B, Kreibich H, Apel H, Barredo JI, Bates PD, Feyen L, Gericke A, Neal J, Aerts JCJH, Ward PJ (2012) Comparative flood damage model assessment: towards a European approach. *Nat Hazards Earth Syst Sci* 12:3733–3752. doi:10.5194/nhess-12-3733-2012

- Kim SM, Benham BL, Brannan KM, Zeckoski RW, Doherty J (2007) Comparison of hydrologic calibration of HSPF using automatic and manual methods. *Water Resour Res*, 43. doi:10.1029/2006WR004883
- Lehner B, Verdin KL, Jarvis A (2008) New global hydrography derived from spaceborne elevation data. *Eos Transactions American Geophysical Union* 89:93–94. doi:10.1029/2008EO100001
- Li XH, Zhang Q, Shao M, Li YL (2012) A comparison of parameter estimation for distributed hydrological modelling using automatic and manual methods. *AMR* 356–360:2372–2375. doi:10.4028/www.scientific.net/AMR.356-360.2372
- Mishra BK, Rafiei Emam A, Masago Y, Kumar P, Regmi RK, Fukushi K (2018) Assessment of future flood inundations under climate and land use change scenarios in the Ciliwung River Basin, Jakarta. *J Flood Risk Manag* 11:S1105–S1115. doi:10.1111/jfr3.12311
- Mohd MSF, Mispan MR, Juneng L, Tangang FT, Rahman NFA, Khalid K, Rasid MZA, Haron SH (2015) Assessment of impacts of climate change on streamflow trend in upper Kuantan watershed. *J Eng Appl Sci* 10:6634–6642
- Nahrim (2010) Reviewed and Updated The Hydrological Procedure No. 1 (Estimation of Design Rainstorm in Peninsular Malaysia)
- Nahrim 2013 Technical Guide: Estimation of Future Design Rainstorm under the Climate Change Scenario in Peninsular Malaysia
- Nashwan MS, Ismail T, Ahmed K (2019) Non-stationary analysis of extreme rainfall in peninsular Malaysia. *J Sustain Sci Manag* 14:17–34
- Noor M, Ismail T, Chung E-S, Shahid S, Sung JH (2018) Uncertainty in Rainfall Intensity Duration Frequency Curves of Peninsular Malaysia under Changing Climate Scenarios. *Water* 10:1750. doi:doi.org/10.3390/w10121750
- Pelaez Jara M (2020) The Ascending and Fading of a Progressive Policy Instrument: The Climate Change Factor in Southern Germany. *Water* 12:1050. doi:doi.org/10.3390/w12041050
- Robi MA, Abebe A, Pingale SM (2019) Flood hazard mapping under a climate change scenario in a Ribb catchment of Blue Nile River basin, Ethiopia. *Applied Geomatics* 11:147–160. doi:10.1007/s12518-018-0249-8
- Sayama T, Ozawa G, Kawakami T, Nabesaka S, Fukami K (2012) Rainfall–runoff–inundation analysis of the 2010 Pakistan flood in the Kabul River basin. *Hydrol Sci J* 57:298–312. doi:10.1080/02626667.2011.644245
- Seong C, Her Y, Benham BL (2015) Automatic calibration tool for hydrologic simulation program-FORTRAN using a shuffled complex evolution algorithm. *Water* 7:503–527.

doi:doi.org/10.3390/w7020503

Shaaban AJ, Amin MZM, Chen ZQ, Ohara N (2011) Regional Modeling of Climate Change Impact on Peninsular Malaysia Water Resources. *J Hydrol Eng* 16:1040–1049. doi:10.1061/(ASCE)HE.1943-5584.0000305

Shrestha S, Lohpaisankrit W (2017) Flood hazard assessment under climate change scenarios in the Yang River Basin, Thailand. *International Journal of Sustainable Built Environment* 6:285–298. doi:10.1016/j.ijsbe.2016.09.006

Shukor MSA, Yusop Z, Yusof F, Sa'adi Z, Alias NE (2020) Detecting Rainfall Trend and Development of Future Intensity Duration Frequency (IDF) Curve for the State of Kelantan. *Water Resour Manage* 34:3165–3182. doi:10.1007/s11269-020-02602-8

Tam TH, Rahman A, Harun MZ, Hanapi S, M. N. & Kaoje IU (2019) Application of Satellite Rainfall Products for Flood Inundation Modelling in Kelantan River Basin, Malaysia. *Hydrology* 6:95. doi:doi.org/10.3390/hydrology6040095

Tan ML, Ibrahim AL, Yusop Z, Chua VP, Chan NW (2017) Climate change impacts under CMIP5 RCP scenarios on water resources of the Kelantan River Basin, Malaysia. *Atmos Res* 189:1–10. doi:doi.org/10.1016/j.atmosres.2017.01.008

Tang KHD (2019) Climate change in Malaysia: Trends, contributors, impacts, mitigation and adaptations. *Sci Total Environ* 650:1858–1871. doi:doi.org/10.1016/j.scitotenv.2018.09.316

Tangang FT, Juneng L, Salimun E, Sei K, Halimatun M (2012) Climate change and variability over Malaysia: gaps in science and research information. *Sains Malaysiana* 41:1355–1366

Tateishi R, Hoan NT, Kobayashi T, Alsaaideh B, Tana G, Phong DX (2014) Production of global land cover data-GLCNMO2008. *Journal of Geography Geology* 6:99. doi:10.5539/jgg.v6n3p99

Wan Zin WZ, Jamaludin S, Deni SM, Jemain AA (2009) Recent changes in extreme rainfall events in Peninsular Malaysia: 1971–2005. *Theor Appl Climatol* 99:303. doi:10.1007/s00704-009-0141-x

Winarta B, Juwono P, Dermawan V, Ali M, Ramli N Flood Inundation Assessment under Climate Change Scenarios in Kuantan River Basin, Malaysia. *IOP Conference Series: Earth and Environmental Science* (2019) IOP Publishing, 012013

Wong CL, Liew J, Yusop Z, Ismail T, Venneker R, Uhlenbrook S (2016) Rainfall characteristics and regionalization in Peninsular Malaysia based on a high resolution gridded data set. *Water* 8:500. doi:doi.org/10.3390/w8110500

Wong CL, Venneker R, Uhlenbrook S, Jamil ABM, Zhou Y (2009) Variability of rainfall in Peninsular Malaysia. *Hydrol. Earth Syst. Sci. Discuss.*, 2009:5471–5503. doi:10.5194/hessd-6-5471-2009

Yahaya NS, Lim CS, Jamaluddin UA, Pereira JJ (2015) The December 2014 flood in Kelantan: A post-event perspective. *Warta Geologi* 41

Zakaria SF, Zin RM, Mohamad I, Balubaid S, Mydin SH The development of flood map in Malaysia. *AIP Conference Proceedings* (2017) AIP Publishing LLC, 110006

Figures

Figure 1

Location of Kelantan River Basin in the map of peninsular Malaysia.

Figure 2

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

Figure 3

Comparison of current and future rainfall depth for 50-year and 100-year return periods.

Figure 4

Comparison of current and future simulated runoff for 50-year and 100-year return periods.

The 50-year and 100-year return period flood depth for the current and future scenarios.

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