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Assessment of rainfall pattern and future change for Kelantan River Basin, Malaysia using statistically downscaled local climate models

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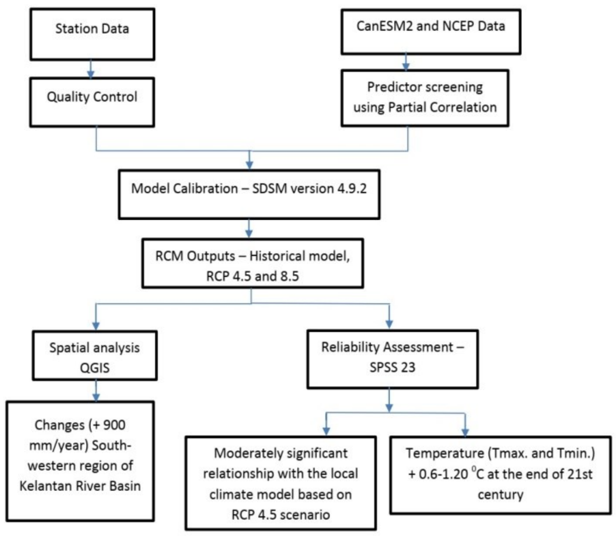
Graphical abstract



Abstract

Climate change has been discussed frequently in recent decades, and it has increased the probability of extreme flood occurrence. This study aims to provide an analysis of future rainfall patterns and flood occurrences specifically for the Kelantan River Basin which is identified as one of flood prone areas in Malaysia. The study area was divided into five regions of the Kelantan River Basin, - Kota Bharu (Northern), Kuala Krai (Center), Pos Lebir (Southeastern), Pos Hua (Southwestern) and Pos Gob (Northwestern). The historical rainfall data (1986-2019) was then retrieved from the Malaysian Meteorological Department (MMD) based on the five regions. The statistical approach was applied to downscaled climate model data from the CanESM2 GCM forced by the Representative Concentration Pathway (RCP) 4.5 and 8.5. The reliability assessment using a Cronbach's Alpha, Linear Regression and Pearson Correlation results show that local climates (2006-2019) forced by RCP4.5 have a similar trend to historical rainfall within the same period. The spatial analysis outcomes showed that the northeastern region of the Kelantan River Basin received its highest average annual rainfall (5,000 mm) in 1990 and caused severe flooding in the area. However, there is a significant change of rainfall pattern in all regions, with a steady increase in annual rainfall in the southwestern region (2021-2100).

Keywords: Kelantan River Basin, statistical downscaling, local climate model, representative concentration pathways (RCPs)

1. Introduction

1.1. Climate change

Climate change is generally considered to result in rising global temperatures and increasing extreme weather occurrence. According to the Intergovernmental Panel on Climate Change's Sixth Assessment Report (IPCC AR6), the Earth's global surface temperature could increase by 1.5°C since pre-industrial era over 20 years due to increasing Greenhouse Gas (GHG) concentration in the atmosphere (IPCC, 2021). The climate system's response to greenhouse gases is estimated with different climate change's impacts. According to Abram *et al*. (2016), anthropogenic effects on climate change are considered to have begun in the early 1830s, when the human society started to change the chemistry of the Earth's atmosphere by adding carbon dioxide (CO_2) to the air.

As a result of increasing global average temperatures, the likelihood of extreme weather occurrence such as abnormal rainfall intensity and increased frequency of heat waves is expected to increase in the future (Haq, 2019). It is much related to climate change in a specific region, and time-period is known as the long-term weather patterns in a particular area (Molloy *et al*., 2017). The warming trend is happening around the world, including Malaysia, as evidenced by temperature observation records of the past 50 years (Tang, 2019; Rahman, 2018). Abnormal rainfall intensity has also been

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observed, which has caused flood and landslide events across Malaysia. Significant flood events have occurred in Johor, Malacca and Pahang flood (18 December 2006), Kedah and Perlis State (11 November 2010), Kelantan (12 December 2014), Penang Island (6 November 2017), Yan District in Kedah State (18 August 2021) and Klang Valley (16 December 2021). According to the Malaysian Department of Irrigation and Drainage (2000), a total of 46% rivers in Malaysia are at the risk of recurrent flooding. The department also stated that approximately 29,800 km^2 (or around 9%) of Malaysia's total land area is vulnerable to flood disasters, including Kelantan River Basin A total of 4.82 million (22% of Malaysia's population) citizens can be affected by flood disasters, especially during the monsoon interchange season that lasts from September to November.

In flood risk management studies, flood risk engineers apply climate model data to assess the likelihood of flood and drought occurrence (Tan and Loh, 2017). Reliable climate models are an important aspect of producing an accurate risk assessment output. Nevertheless, developing a highly reliable climate model is a major concern for hydrologists and governmental authorities to reduce the flood risk. The General Circulation Model (GCM) has been adopted by the IPCC to assess the future climate trend based on specific radiative forcing. However, the drawback of GCMs are their low spatial resolution (200-300 km), which makes resolving local weather and hydrologic profiles difficult. To address this problem, downscaling must be conducted in order to apply GCMs onto a finer resolution (50-100 km), enabling a better representation of local landscapes (Trzaska and Schnarr, 2014).

Ang (2016) applied the statistical downscaling method on General Circulation Model (GCM) data with Canadian Earth System Model (CanESM2). Statistical downscaling is a method used to downscale the spatial of GCMs that are coarse into finer one, which is most extensively used approach for assessments of climate and hydrology (Chen *et al*., 2018). It is a useful concept since it defines regional climate variables that are influenced by large-scale predictors and local-scale variables with observed data (Doury *et al*., 2023). The results indicated that significant increases of average temperature, and consequently increases of Potential Evapotranspiration (PET), cause water to be lost through evaporation over a vegetated surface or green crop. Other discussion was made by Fung *et al*. (2019); their study demonstrated an approach to statistically downscale the CanESM2 based on the Representative Concentration Pathway (RCP) 8.5. The regionalized rainfall pattern and temperature produced by the model showed an increase temperature over the Langat River Basin for the 2021-2050 period. The study also synthesized the model outputs with other climatic indices i.e PET and Standardized Precipitation Evapotranspiration Index (SPEI). Moreover, Tahir *et al*. (2017) assessed severity of rainfall by downscaling the CanESM2 based on Representative Concentration Pathways (RCPs) 2.6, 4.5 and 8.5 in Limbang River basin. The result obtained that the future rainfall data (2006 – 2100) was then compared with the baseline period (1976-2005), indicating that rainfall intensity could continue to increase in future and directly affects the likelihood of flood occurrence in Limbang River basin. Furthermore, Vu *et al*. (2016) applied high spatial and temporal resolutions Regional Climate Model (RCM) to develop the Intensity-Duration-Frequency (IDF) curves. The 6 hourly rainfall annual maximum rainfall intensity output shows that there is high likelihood of flood events in Hanoi city in future for 10-200 years return periods. Other impacts studies such as Hassan and Harun (2011), Reder *et al*. (2020), Senamhi (2014) and Jacobeit *et al*. (2014) support the feasibility of analyzing the climatic hazard of drought and flood events using downscaled climate models.

Flooding is recognized a major natural disaster in Kelantan River Basin (Arham *et al*., 2020; Tam *et al*., 2021). The region experiences two monsoon seasons which are the southwest monsoon (April to August) and the northeast monsoon (October to January). The rainfall intensity of the northeast monsoon (1,530 mm/year) is higher than that of the southwest monsoon (993 mm/year). The region has an annual rainfall of about 2,940 mm (Wong *et al*., 2016). According to a National Water Resources Study, the low-lying downstream portion of the basin (760 km^2 land area) is prone to annual floods, the worst of which happened in 2014, which displaced around 202,000 people and caused 13 deaths (Baharuddin *et al*., 2015). Flooding not only interferes with economy and destroys infrastructure, but also causes the disruption to healthcare and to public operations. Total financial losses caused by flooding are estimated to be about RM915 million every year and affects the state gross domestic product (Ghani *et al*., 2009). Moreover, there is absence of a local climate model to predict the future rainfall variation for Kelantan River Basin. Hence, the aim of this study is to enhance the flood forecasting capabilities in Malaysia by developing a suitable and appropriate climate scenario for future projection (2020- 2100). This study aims to develop a local climate model based on CanESM2 using Statistical Downscaling Methods and to analyze the potential future trend based on a selected RCP for the Kelantan River Basin.

1.2. Background of Kelantan River Basin

The Kelantan River Basin is located between latitudes 4° 40' and 6° 12' North, and longitudes 101° 20' and 102° 20' East, at the northeastern region of Peninsular Malaysia. It has a total catchment area of about 13,135 km^2 and covers approximately 85% of the Kelantan State land area. The catchment rises from the southern portion of Kelantan State, and mainly consists of steep forested land. As shown in Figure 1, it is drained by the Kelantan River, which is about 248 km long and flows northward into the South China Sea (Ghorbani *et al*., 2015). Two tributaries have been identified as the Galas River and the Lebir River. The dividing point of the Kelantan River into the Galas and Lebir Rivers is located about 100 km from the river mouth at Kuala Krai District. The Galas River is composed of the Pergau and Nenggiri Rivers. According to the Department of Statistics Malaysia (2020), the population living around there is about 1.90 million people. The Socioeconomic activity in this region relies mainly on the agriculture sector such as paddy, vegetable, rubber, and oil palm plantation. The Kelantan River basin is also important to fishing and livestock farming.

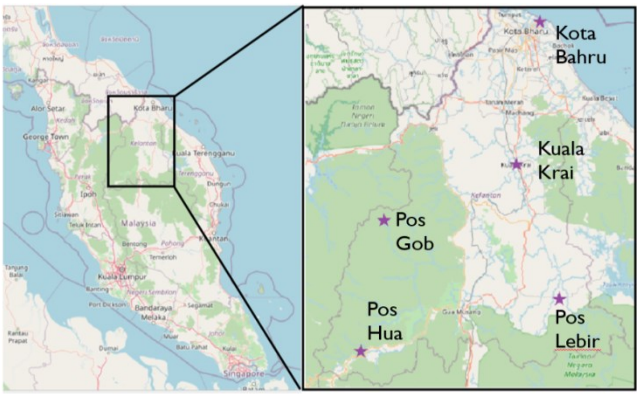


Figure 1. Location of Selected Stations Representing the Kelantan River Basin (Edited from Hashim, 2015)

2. Methodology

In this study, the five weather stations in Kelantan River Basin were chosen to represent different regions in the basin. The observed daily rainfall and daily minimum temperature (Tmin.) and maximum temperature (Tmax.) data were collected from the Malaysian Meteorological Department (MMD). These stations are located at the areas which represent the northern, center, southeastern, southwestern and western of the basin as shown in Table 1. In order to generate the local climate model based on RCP 4.5 and 8.5, the GCM CanESM2 was applied in the downscaling work. Data for a total of 26 atmospheric predictors (in Table 2) were downloaded from National Centres for Environmental Prediction (NCEP) and National Centre for Atmospheric Research (NCAR) online portal (https://climate-scenarios.canada.ca/?page=pred-canesm2), based on grid Box_37X_34Y and Box_37X_35Y.

Table 1. Selected MMD Stations located in Kelantan River Basin

NO	Station No	Station Name	Record period (19** - 20**)	Duration (years)	Latitude	Longitude	Region
1	48615	Kota Bharu	1986 – 2019	34	06° 10' N	102° 18' E	Northern
2	48616	Kuala Krai	1986 –2019	34	05° 32' N	102° 12' E	Central
3	40470	Pos Lebir	1986 – 2013	28	04° 56' N	102° 23' E	Southeastern
4	40516	Pos Gob	1986 – 2019	34	05° 17' N	101° 38' E	Western
5	40433	Pos Hau	1986 – 2019	34	04° 42' N	101° 32' E	Southwestern

2.1. *Experimental setup*

The Statistical DownScaling Model (SDSM) software ver. 4.6 was used to implement Statistical Downscaling Methods on the collected climate data, thus producing high-resolution climate information for the Kelantan River basin. The station data collected from MMD underwent quality control function using SDSM software, where missing and errors data were identified, as well as data treatment were performed if any missing found in the dataset.

The 26 predictors were screened by applying partial regression analysis, in order to identify the predictors which have statistically significant relationship with the local climatic condition. The obtained partial regression coefficients (r) and p-values allowed the predictors with significant relationships with the local climate condition to be selected for the downscaled model. High magnitude values of r accompanied by statistically significant p-values ($p < 0.05$) suggest non-random relationships between pairs of predictors. In this study, the partial correlation was carried out using SPSS ver.23 software to select the predictors that meet the above-defined screening criteria. As shown in Table 2, a total of 5 predictors for the rainfall model and 7 predictors for temperature model were identified as having statistically significant relationship with the station data. The selected predictors were loaded into model calibration and then the weather generator to produce 20 ensemble models of synthetic daily weather sequences based on RCP 4.5 and 8.5 scenarios for 2006-2100 period. The RCP 2.6 scenario was not chosen as it represents strict mitigation scenario, which aims to likely limit global warming to 2°C above pre-industrial baseline temperatures. A vast majority of models state that by 2100, scenarios with similar forcing levels to RCP 2.6 are expected to produce considerable net negative emissions, which is not reasonable, whereas RCP 4.5 and 6.0 both indicates intermediate scenarios, thus only RCP 4.5 was chosen. The model outputs were then validated by comparing the variation of monthly trend between simulated historical model and observation data for 1986-2005 period.

To assess the local climate model's performance i.e reliability and consistency, three assessment methods, Cronbach's Alpha statistical analysis (α), linear regression (R^2) and Pearson correlation (r) were applied in this study based on Mutayoba & Kashaigili (2017), Donges *et al.* (2009) and Zhao (2014). Based on the assessment outcomes, the RCP scenario with stronger reliability, which resembles more of the observed data, was recommended to represent the local climate model for Kelantan River Basin. The linear regression test is feasible to analyze historical observation with and weather forecasting (Mahamad 2015; Zhou *et al.*, 2017). In the linear regression, Y represents the dependent variable while X represents the independent variable, so under the relationship of both X and Y., the simple regression model of X and Y is showed as below:

$$Y = \alpha + \beta X \tag{1}$$

Where:

Y = dependent variable (Model output)

X = independent variable (Historical observation)

α = Regression coefficients

β = Regression coefficients

Coefficient values represent the strength and direction of the relationship between the dependent variable and the independent variable(s). The representativeness of the regression line's fit of the data is determined by calculating a coefficient of determination, R^2.

To quantify the strength of the relationship between two variables, Pearson correlation was applied in this study. Pearson coefficient value (-1.0 or 1.0) indicates strongest correlation, and the negative value indicates the inverse relationship between two variables. Besides, reliability Cronbach's Alpha was conducted to determine the strength of consistency between the model and observation data in this study. Theoretically, it can be interpreted based on the Cronbach's Alpha value as low consistency (0.0 – 0.2), rather consistency (>0.2 – 0.4), moderate consistency (>0.4 – 0.6), consistency (>0.6 – 0.8) and high consistency (>0.8 – 1.0) (Ahdika, 2017).

For an effective flood risk management, it is crucial to understand the variation of rainfall intensity based on future climate. Spatial analysis was conducted using the Quantum Geographical Information System (QGIS). QGIS is able to synthesize given vector datasets (the datasets that inform the local climate model) using an Inverse Distance Weighted (IDW) interpolation method, thereby generating and exporting graphical maps i.e., 20- year-interval rainfall pattern maps for the Kelantan River Basin. The observation data were weighted during interpolation process that the influence of other location (x). The estimation of the value z at location x is a weighted mean of observations.

$$\hat{z}(X) = \frac{\sum_{i}^{n} w_i z_i}{\sum_{i}^{n} w_i} \tag{2}$$

$$w_i = | x - x_i |^{-\beta} \tag{3}$$

where β≥0 and |·| corresponds to the Euclidean distance. The inverse distance power, β, determines the degree to which the nearer location(s) are preferred over more distant points (Hartmann *et al.*, 2018).

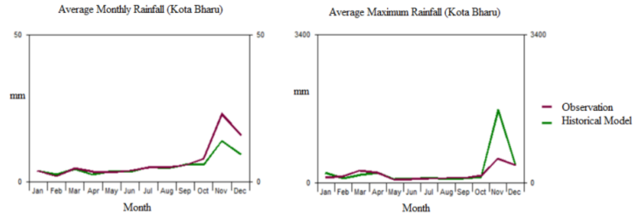
Table 2. The 26 NCEP (National Centres for Environmental Prediction) Predictors

No	Predictors	Code	No	Predictors	Code
1	#Mean sea level pressure	mslpgl	14	500hPa Divergence of true wind	p5zhgl
2	1000hPa Wind speed	p1_fgl	15	850hPa Geopotential	p800gl
3	10000hPa Zonal wind component	p1_ugl	16	850hPa Wind speed	p8_fgl
4	*#10000hPa Meridional wind component	p1_vgl	17	#850hPa Zonal wind component	p8_ugl
5	10000hPa Relative vorticity of wind	p1_zgl	18	#850hPa Meridional wind component	p8_vgl
6	10000hPa Wind direction	p1thgl	19	*850hPa Relative vorticity of wind	p8_zgl
7	*10000hPa Divergence of true wind	p1zhgl	20	850hPa Wind direction	p8thgl
8	#500hPa Geopotential	p500gl	21	850hPa Divergence of true wind	p8zhgl
9	500hPa Wind speed	p5_fgl	22	*Total precipitation	prcpgl
10	500hPa Zonal wind component	p5_ugl	23	500hPa Specific humidity	s500gl
11	500hPa Meridional wind component	p5_vgl	24	* 850hPa Specific humidity	s850gl
12	500hPa Relative vorticity of wind	p5_zgl	25	#1000hPa Specific humidity	shumgl
13	500hPa Wind direction	p5thgl	26	#Air temperature at 2m	tempgl

**Statistically significant predictors - Rainfall; # Statistically significant predictors - Temperature*

3. Results and discussion

The statistical validation is employed to study level of consistency for developed historical model as shown in Figure 2. The average maximum monthly rainfall model shows the major outlier for Pos Hua station and certain periods such as Pos Lebir station (May-July period), Kota Bahru, Kuala Krai and Pos Lebir (October -December period). It gives a major difference between the observation data and the historical model can up to 1,000 mm during November-December. The reliability study of trends in the CMIP5 model ensemble of IPCC Assessment Report (AR5) discovers that the temperature trends are locally reliable under the CMIP3 ensemble, but when being normalized by the mean global temperature, the ensemble tends to be overestimated in local models (Van Oldenborgh, *et al.*, 2013). Besides, due to the confined spatial variability of warming patterns, the precipitation trends may be also overestimated too (Sakaguchi *et al.*,2012). The overconfidence can be explained by following approaches such as the underestimation of low-frequency natural variability by model (Knutson, *et al.*, 2013); sensitivity of model to those aerosols forcing and lastly, the patterns change due to the inappropriate represented greenhouse warming local effects. In this study, major outlier is detected for average monthly maximum rainfall (1984-2005) in all stations. The average monthly rainfall data generated from Pos Hua and Pos Lebir historical model are recorded as different values compares to Malaysia Metrological Department's observation data. Based on historical model, the average maximum monthly rainfall of Pos Lebir shows an underestimation result approximately 250 mm for June, November, and December. These phenomena can be explained by the effect of the La Nina, El Nino and anomalous Northeast monsoon season that occurred during 1988 – 1989 and 1999 – 2001 (Karim *et al.*, 2016; Mohamad *et al.*, 2012). The CanESM2 may not be able to systemize the extreme weather phenomena occurred in Malaysia. However, the validation outcomes show that average monthly rainfall models are determined as high consistency for all regions. Thus, the developed RCMs are valid for rainfall pattern analysis.



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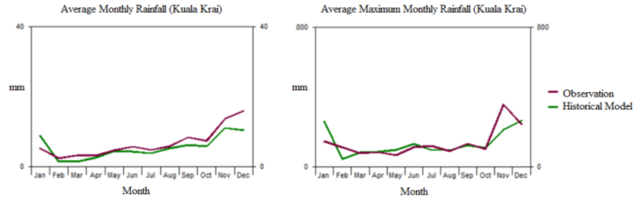

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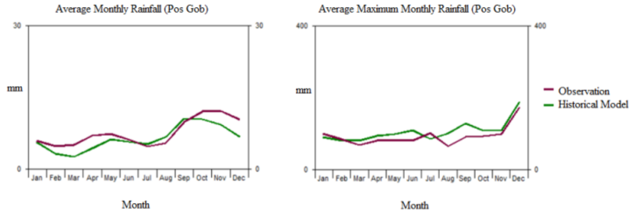

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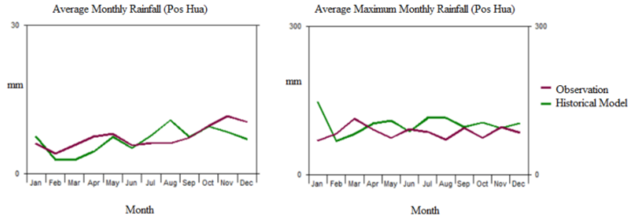

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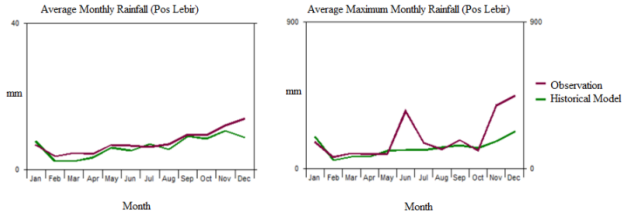


(e)

Figure 2. Comparison of average monthly rainfall and maximum monthly Rainfall (1986-2005) for (a) Kota Bahru, (b) Kuala Krai, (c) Pos Gob, (d) Pos Hua, (e) Pos Lebir

For determination of future rainfall pattern, the reliability assessment consists of three analysis method i.e. Cronbach's alpha statistical analysis (α), linear regression (R^2) and Pearson correlation (r) are applied on the downscaled regional climate model based on Representative Concentration Pathway (RCP) 4.5 and 8.5 scenario. The Cronbach alpha and Pearson correlation assessment output shows there are strong and moderate relationship between observation (2006-2019) and RCPs for Kota Bharu, Kuala Krai, and Pos Lebir, with the α value ≥ 0.6 and r value ≥ 0.5 respectively (Table 2). However, all five stations do not achieve R^2 (>0.4) in linear regression analysis. According to Ritter and Muñoz-Carpena (2013), the R^2 value quantify the goodness-of-fit between dependent and independent variables which is not the quality of the model. Although the result shows that low R^2 value (0.39), it may be suitable to examine the reliability level of RCMs as this study is to examine the future rainfall variation. At the same time, these models can be considered as consistent with observation data if the alpha (α) value ≥ 0.6. In this study, the outputs of the linear regression show all the models are significant and reject the sensitivity prediction depressive symptoms (Baguley, 2009). However, the linear regression gives a lot of information of the reliability assessment such as the significant model and adjusted R-squared (R^2).

Table 3. Reliability Assessment of Local Climate Model (Rainfall) for Kelantan River Basin

Model	RCP Scenarios	Statistical Analysis – Cronbach's Alpha (α≥ 0.6)	Linear Regression ($R^2 \geq 0.4$, Sig.)	Pearson Correlation Coefficients (r ≥ 0.5)
Kota Bharu	4.5	0.68*	0.26, 0.001	0.51*
	8.5	0.58	0.17, 0.001	0.41
Kuala Krai	4.5	0.73*	0.39, 0.001	0.62*
	8.5	0.66*	0.28, 0.001	0.53*
Pos Gob	4.5	0.53	0.17, 0.001	0.41
	8.5	0.52	0.15, 0.001	0.38
Pos Hua	4.5	0.46	0.10, 0.001	0.30
	8.5	0.30	0.06, 0.002	0.25
Pos Lebir	4.5	0.66*	0.26, 0.001	0.51*
	8.5	0.60*	0.25, 0.001	0.50*

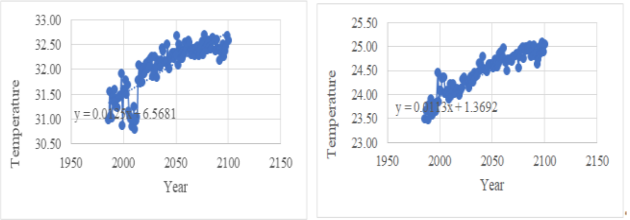
By comparing the reliability assessment outputs, the downscaled regional climate model for Pos Gob and Pos Hua shows the low reliable level for both RCP scenario. The cronbach alpha (α) and Pearson correlation coefficients (r) do not fulfill the pre-defined criteria (α≥ 0.6; r ≥ 0.5). However, the outputs of these reliability test cannot conclude the analysis outcomes, and thus the further step is carried out to retrieve the summary of monthly rainfall trend and to determine the basic cause of this problem (Ng *et al.*, 2023). As shown in Kota Bharu, Kuala Krai and Pos Lebir station, the Linear regression (R^2) and Pearson correlation (r) result shows statistically significant that local rainfall pattern may follow the RCP4.5 scenario.

Besides, the study also analyses the temperature variation based on similar statistical reliability assessment methods. Based on result as shown in Table 3, there are the significant reliability level of maximum temperature (Tmax.) and minimum temperature (Tmin.) for all stations. The result indicates that the total 90% of RCMs based on RCP4.5 scenario are relatively reliable compares to the RCP8.5 scenario except for minimum temperature (Tmin.). The RCP4.5 scenario would still be valid to represent minimum temperature in the river basin (Table 4).

Table 4. Reliability Assessment of Local Climate Model (Temperature) for Kelantan River Basin

Model	RCP Scenarios	Statistical Analysis – Cronbach's Alpha (α≥ 0.6)	Linear Regression ($R^2 \geq 0.4$, Sig)	Pearson Correlation Coefficients (r ≥ 0.5)
Kota Bharu (T_{max})	4.5	0.94*	0.79*, 0.001	0.89*
	8.5	0.92*	0.74*, 0.001	0.86*
Kota Bharu (T_{min})	4.5	0.75*	0.40*, 0.001	0.62*
	8.5	0.82*	0.51*, 0.001	0.72*
Kuala Krai (T_{max})	4.5	0.90*	0.67*, 0.001	0.82*
	8.5	0.87*	0.62*, 0.001	0.79*
Kuala Krai (T_{min})	4.5	0.78*	0.40*, 0.001	0.63*
	8.5	0.85*	0.54*, 0.001	0.74*

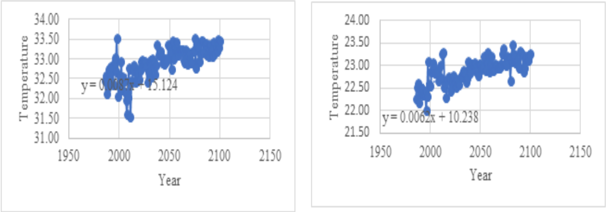
*Note: * indicates values that statistically significant for reliability level*



(a)¶

(b)¶

Figure 3. Local Climate Model for Kota Bharu based on RCP4.5 (2014-2100) (a) Tmax. (b) Tmin



(a)

(b)

Figure 4. Local Climate Model of Kuala Krai based on RCP4.5 (2014-2100) (a) Tmax. (b) Tmin

The Local Climate Model (Tmax. and Tmin.) based on RCP4.5 (2014 – 2100) was interpreted using line graphs which are shown in Figures 3 and 4, respectively. There are positive linear trendline for Northern region (Kota Bharu) $Y_{Tmax.}= 0.0125X + 6.5681$; $Y_{Tmin.} = 0.0113X + 1.3692$ and Center region (Kuala Krai) $Y_{Tmin} = 0.0062X + 10.238$; $Y_{Tmax} = 0.0087X+ 15.124$. These results indicate that atmospheric temperature may increase by $0.6\text{-}1.2^{0}$C at the end of 21st century. The projection tallied with the increase of atmospheric temperature with minimum 1.5°C reported by the IPCC (2021) and Tan *et al*. (2021). The Kelantan River Basin may experience more frequent and intense rainfall during the Northeast monsoon season and prolonged during the El Nino period. Precipitation intensity and frequency can be affected by climate change, where warmer oceans cause larger amount of water to be evaporated into the air, resulting in heavier rain. The change of weather condition and climate variability will also contribute number of extreme flood events as well as impacted to the agriculture and water resources in the study area.

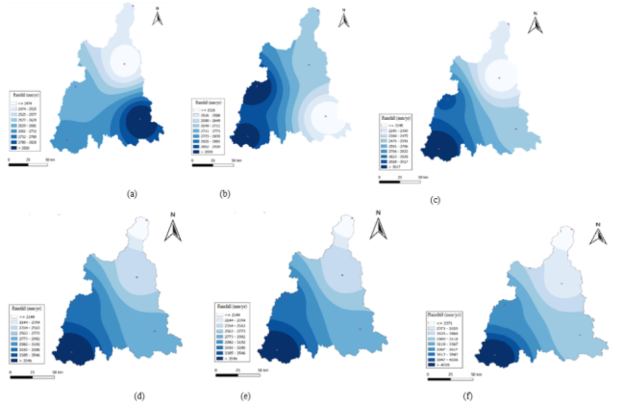


Figure 5. Spatial Analysis Average of Annual Rainfall of the Kelantan River Basin (a) 1986 - 2000 (b) 2001-2020 (c) 2021-2040 (d) 2041-2060 (e) 2061-2080 (f) 2081-2100 Period

The Local Climate Models of the annual rainfall pattern in different regions based on RCP4.5 (2020 – 2100) was descriptively analyzed in this study. The anomalous rainfall pattern (>4,000mm/year) was projected for Northern region (Kota Bharu station) i.e 6,206 mm (2034), 4,320mm (2054). However, the future rainfall pattern remains stable throughout 21st century. The application of spatial analysis using the IDW approach was conducted to visualize the past and future rainfall pattern within 20-year interval. Figure 5 illustrates the results from the spatial analysis of average of annual rainfall of Kelantan River Basin (1986-2100). Based on the spatial analysis outputs, there could be large changes in rainfall patterns over the Kelantan River Basin. The Southeastern region (Pos Lebir station) recorded highest average annual rainfall (5,000 mm) in 1990 and caused severe flooding in the location. The observation dataset and projected local climate models show a steady trend of increasing rainfall in all regions after the anomalous rainfall events in 1990 and 2014. Concerning future rainfall trends (2021-2100), an anomaly of rainfall intensity is detected in the Southwestern region (Pos Hua and Pos Gob station) in Kelantan River Basin particularly in the period of 2021-2040, 2041-2060, 2061-2080 and 2081-2100. The outcome corresponds to the findings of Tan *et al* (2017) and Armain *et al* (2021), where the annual rainfall is projected to increase in coming years. It may increase the flood risk in the Kelantan State Capital (Kota Bahru) which located at the downstream of the Kelantan River Basin.

4. Conclusions

The local climate models were developed from CanESM2 RCP4.5 and 8.5 by statistical downscaling methods for the Kelantan River Basin. The Local Climate Model based on RCP4.5 and 8.5 scenarios were tested for reliability. The performance of model was analysed by the reliability statistic – Cronbach's Alpha, linear regression and Pearson correlation coefficients method. The assessment outputs indicate the local climate condition has moderately significant relationship with the local climate model based on RCP 4.5 scenario. The atmospheric temperature (Tmax. and Tmin.) may be increased by 0.6-1.2^{0}C at the end of 21st century. The model projects a significant change in future rainfall patterns in the Southwestern Region of the Kelantan River Basin. This increase in rainfall intensity is projected to potentially occur in the upstream of Kelantan River Basin. It may induce the flood risk in the Kelantan State Capital (Kota Bahru), Tanah Merah, Pasir Mas, and Kadok which are located at the downstream of Kelantan River Basin.

The developed local climate models based on the CanESM2 RCP4.5 and 8.5 is identified as the major limitation in this study. It is important to carry out a comparison study with the latest release of Canadian Earth System Model-CanESM5. Since it has higher equilibrium climate sensitivity (5.6 K) compares the predecessor-CanESM2 (3.7k), further studies are suggested to statistically downscale the CanESM5 and replicate the historical rainfall, Tmax. and Tmin. over the Kelantan River Basin based on Shared Socio-economic Pathways (SSP 2–4.5 and 5–8.5). So that, the inter-comparison works can be carried out to determine the performance and sensitivity between RCPs and SSPs scenario.

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