sciendo

Civil and Environmental Engineering
Vol. 18, Issue 1, 221-233, DOI: 10.2478/cee-2022-0021

ASSESSMENT OF THE FLOOD AND DROUGHT OCCURRENCE USING STATISTICALLY DOWNSCALED LOCAL CLIMATE MODELS: A CASE STUDY IN LANGAT RIVER BASIN, MALAYSIA

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Abstract

Climate change is a complex and multi-layer issue with global and local entanglement. In this study, Langat River Basin is chosen. Secondary data was used including the historical flood and drought event reports, Standardized Precipitation Index-1 data and Canadian Earth System Model (CanESM2) along with Australian Community Climate and Earth System Simulator Coupled Model (ACCESS CM-2). These data were used to determine the monthly flood and drought precipitation risk based on five regions of Langat River Basin. The CanESM2 and ACCESS CM-2 based on RCP 4.5 and RCP 8.5 scenarios were downscaled and bias corrected for this study. The reliability of these models was then analyzed with Pearson correlation and probability density function (PDF). The future flood and drought risks from year 2020 to 2100 were predicted using the most reliable local climate model local climate hazard thresholds. The CanESM2 RCP 4.5 scenario was identified to have moderate relationship with the historical precipitation trend in Langat River Basin. The Pearson correlation outcomes were then verified by analyzing the PDF curve between models and historical precipitation. The result shows that the downscaled CanESM2 RCP 4.5 was determined to have moderate correlation r = 0.30, whereas highest similarity with the historical precipitation trend 98.63 % based on 2006 to 2018 period. The scenario is consistent with medium emission coupled with increasing mitigation efforts in Malaysia. Furthermore, the flood and drought risk assessment outcomes show that the occurrence rate for Central, Northern, Southern, Western, and Eastern region in Langat River Basin were determined as 41.97 %, 60.19 %, 40.23 %, 20.16 %, and 34.98% respectively. The Central region was predicted having two drought incidences (February 2069 and February 2099) due to extreme dry season predicted based on 2020 to 2100 period.

Keywords:

Statistical downscaling;
Regional climate model;
Potential flood and drought risk;
Langat River Basin;
Malaysia.

1 Introduction

Langat River Basin has been experiencing numerous flood events with the worst floods happening on 17 - 18 December 2021 [1]. Selangor has recorded higher and increasing occurrence of extreme hazards like flash floods in recent years. Hulu Langat District is one of the most susceptible districts in the Langat River Basin. The occurrence of recurring flash floods is due to the area's physical factor and heavy precipitation. Heavy precipitation during high tide would lead to higher risk of flash flood. As the increasing occurrence of climate hazards such as flash floods and drought can cause great fatalities, properties and economic losses to Langat River Basin, the relationship of climate change and climate hazards in Langat River Basin needs to be studied to explain the cause of the trend.

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The Southeast Asia region is identified as high likelihood of climate induced disasters i.e. flood and drought to due to climate change effects. To reduce climate disaster risk, future rainfall intensity must be determined based on local scale climate model [2]. Different studies in assessing the relationship between climate change and climate hazards have been done globally using climate models and representative concentration pathways (RCPs) scenarios. Most findings revealed that the frequency and the magnitude of climate hazards will increase in the future due to climate change. Piras et al. used General Circulation Model (GCM) and Regional Climate Model (RCM), statistical downscaling and hydrologic model to predict precipitation patterns and flood frequencies in a Mediterranean basin and found out that impermeable and flat sub-basins will have more severe flood events in 2041 to 2070 based on A1B emission scenario [3]. Meanwhile, a more permeable and steep sub-catchments will experience an opposite trend.

Suppiah et al. identified that high climate hazard risk was determined for Cameron Highlands [4]. Tang reviewed studies on past and future trends of climate change in Malaysia indicated that extreme events frequency will increase in future while precipitation showed variability [5]. Extreme events include high temperature, high precipitation, dry spell, thunderstorm and strong winds. Huang et al. found the high variation of precipitation in Langat River Basin by using downscaled CanESM 2 RCP 8.5 scenario. The drought indices SPI-1 is found to be feasible for monitor future drought events in the study area [6]. Other similar studies were conducted e.g. water resources changes in Peninsular Malaysia using climate model projection [7, 8] and rainfall projection using PRECIS SRES scenario in highland region [9]. A tropical country like Malaysia was found to have higher likelihood of flood occurrence throughout a year, but prediction of future climate hazards using local climate models have not been conducted yet. Therefore, the assessment of relationship between climate change and climate hazards should be studied at lower scales using RCM and local level in Selangor to accurately access the spatial variability regarding future climate hazards trend.

The aim of this study is to analyze the reliability of statistically downscaled local climate model (RCM) for Langat River Basin, to determine climate hazards precipitation threshold in Langat River Basin, and to predict future flood and drought risks in Langat River Basin. This study focuses on the reliability assessment of two assemble regional climate models namely ACCESS-CM2 and CanESM2.0 based on RCP 4.5, RCP 8.5 scenario. The flood and drought event threshold are determined by analyzing the historical record occurs in Langat River Basin.

2 Background of Langat River Basin

Langat River Basin was selected as the study area as it has a frequent occurrence of flood and drought events [10]. Langat River has a main river course length of 141 km, mainly located approximately 40 km east of Kuala Lumpur (latitudes $2^{o}40'152"$ N to $3^{o}16'15"$ N and longitudes $101^{o}19'20"$ E to $102^{o}1'10"$ E). It is a transboundary river basin which has a total catchment area of about 1,815 km^2 [10]. The river originates at the Titiwangsa range of Peninsular Malaysia, flows westward through three separate state administrations (Selangor State, Negeri Sembilan State and Putrajaya Federal Territory) and exit at Malacca Strait. There are two water dams in the river basin, namely the Langat Dam and Semenyih Dam which have a catchment area of 54 km^2 and 41 km^2, respectively [10]. Both dams are used for water supply such as water consumption for residents, agriculture or irrigation, and also for factories in Langat River Basin

The river basin has recorded high average and consistent yearly temperature, high precipitation, and humidity. The annual mean precipitation is recorded as 2,019.3 mm. The mean of maximum temperature and minimum temperature is recorded as 32.1 °C and 24.4 °C respectively. Its wet season is from November to March and dry period is from May to September. The weather is affected by the southwest Monsoon blowing across the Straits of Malacca. The location of meteorological monitoring stations in Langat River Basin is shown in Fig. 1.

In term of socioeconomic, Langat River Basin has a population of around 1.2 million in 2006, with a 7.64 % growth rate. It is projected that the population will increase to 1.5 million in 2015. The Langat River is one of the primary rivers covering the urban area of Selangor that has high population. Langat River has provided water resources to about half of the population of Selangor over the past 40 years. It is the main water source for Selangor. More than 66 % of the Selangor population reside the floodplain due to the fertile soil for agriculture, housing, recreation, and industrial developments. Selangor is the most developed state in Malaysia with complete infrastructures such as highway and public transport. It is also the largest economical state in Malaysia as it is the top gross domestic

product (GDP) contributor to Malaysia, making up 22.7 % of the country's GDP with RM239.96 billion in 2015 [11].

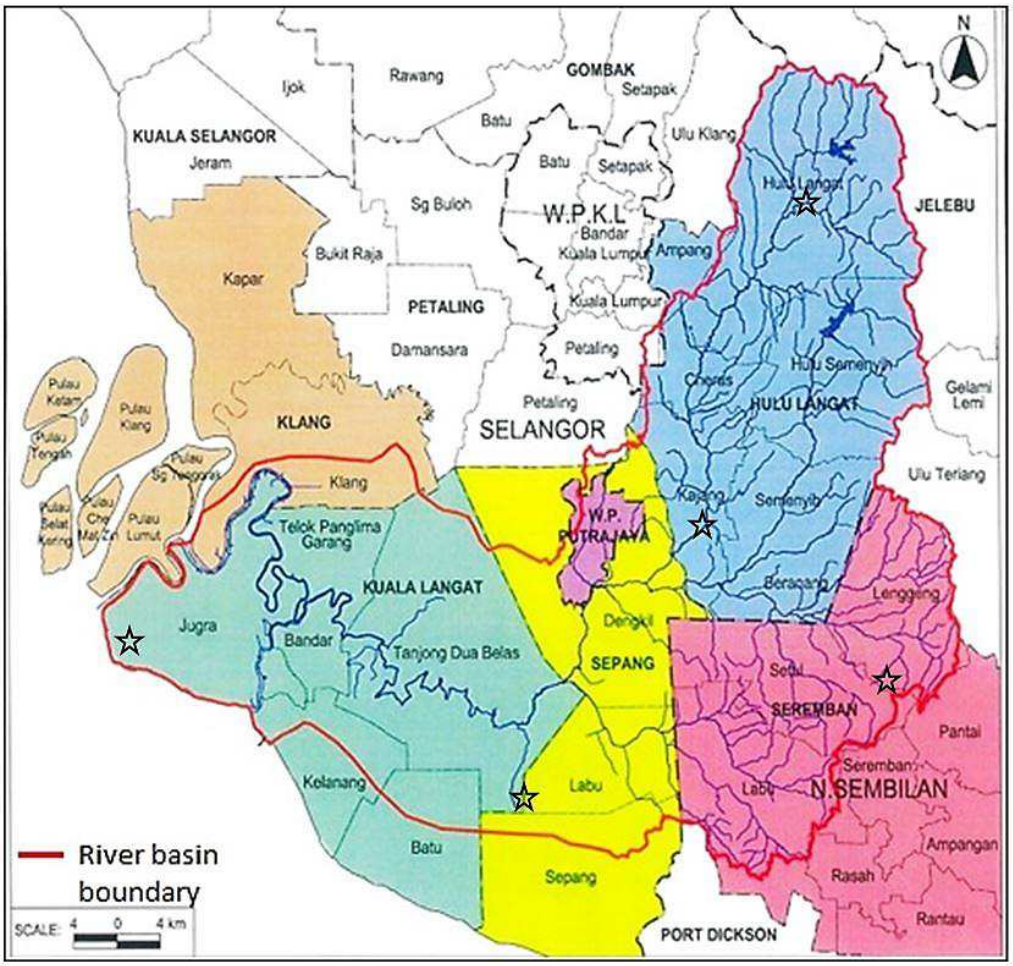


Fig. 1: Langat River Basin with indication of different districts and state boundaries [12]. The asterisks indicate the location of meteorological monitoring stations in the Langat River Basin.

3 Methodology

3.1 Data collection

Secondary data were used in this study. All secondary data was obtained from different sources as shown in Table 2. A total of five station data were used in this study which represents different regions of Langat River Basin as shown in Table 1. The Malaysian Meteorological Department (MMD) provided the historical temperature and precipitation data with a daily temporal resolution (1983-2018). Meanwhile, the record of flood events and drought events for 2000 - 2018 period was retrieved form Department of Irrigation and Drainage (DID). The occurrence dates and locations of the climate hazards were also obtained from the DID.

For the General Circulation Model (GCM) - CanESM2 and ACCESS-CM2, the period of the data was used based on the 1983 to 2018 period, as corresponding to availability of historical precipitation data collected from MMD. This CaneESM2 dataset was downloaded from the Canadian Climate Data and Scenarios website (climate-scenarios.canada.ca/?page=pred-canesm2) (Canadian Climate Data and Scenarios, 2019). The Australian Community Climate and Earth System Simulator Coupled Model (ACCESS CM-2) was provided by National Hydraulic Research Institute of Malaysia.

On top of that, the standardized precipitation Index-1 (SPI-1) and standardized precipitation Index-3 (SPI-3) for Langat River Basin from the year of 1983 to 2016 were sourced from Ang [13]. The SPI-n is a ratio between total precipitations received at the specific location during a period of months with the long-term rainfall distribution. It was applied to determine the flood and drought risk in Langat River Basin.

Table 1: Station data based on different regions of Langat River Basin.

Station data	Region of Langat River Basin
Sepang	South
Seremban	East
Hulu Langat	Central and North
Kuala Langat	West

Table 2: Secondary data obtained from different sources.

Secondary data	Sources
1 Flood data record (2000- 2018)	Department of Irrigation and Drainage Ampang, Malaysia
2 Drought data record (2000 -2018)	Department of Irrigation and Drainage Ampang, Malaysia
3 Malaysia temperature and precipitation record (1983 – 2018)	Malaysian Meteorological Department (MMD), Malaysia
4 Standardized precipitation Index-n (SPI-n) data (1983 to 2016)	Ang [13]
5 Second generation Canadian Earth System Model (CanESM2) - Reanalysis with atmosphere horizontal resolution 2.8^{o}lat. ×2.8^{o}long)	CanESM2 online portal (https://climate-scenarios. canada.ca/?page=pred-canesm2)
6 Australian Community Climate and Earth System Simulator (ACCESS -CM-2) - with atmosphere horizontal resolution 1.9^{o}lat ×1.2^{o}long)	National Hydraulic Research Institute of Malaysia (NAHRIM), Malaysia

3.2 Data analysis and synthesis

The data processing to obtain climate hazard precipitation threshold in this study was performed using the Microsoft Excel with Data Analysis Tool Pack extension. It utilizes the mean, standard deviation, bias correction, Pearson correlation, linear regression of historical precipitation with different representative concentration pathway (RCP) scenarios and prediction of climate hazard risk by generating descriptive charts. In contemplation to produce a reliable local climate model, an assemble modeling approach is the key for a reliable impact assessment [14]. CanESM2 and ACCESS-CM2 model were statistically downscaled by stochastic techniques. It was conducted using SDSM ver 4.3 software. All the model outputs were based on Representative Concentration Pathways (RCP) 4.5 and 8.5. It was used to artificially inflate the variance of the downscaled daily time series to better accord with observation [24]. Total of four local climate models (CMs) were statistically downscaled in this study which refers as CanESM2 RCP 4.5, CanESM2 RCP 8.5, ACCESS-CM2 RCP 4.5 and ACCESS-CM2 RCP 8.5.

The model output for each CM consists of 20 assemble models for daily precipitation based on 2006-2100 period. The 20 assemble models exhibit different biases and show mixed results in the model output. Therefore, these biases were reduced by obtaining the averages of all assemble models and then bias corrected by using Equation (1). Bias correction is crucial to eliminate the system error and improve the accuracy of downscaled RCMs, more suitable for impact studies [15]. The bias correction equation in Equation (1) was applied based on Terink et al. [16].

$$P' = \left(\frac{\bar{P}_{sim}}{\bar{P}_{obs}}\right) \times P \ , \tag{1}$$

where:
P - corrected precipitation,
$\bar{P}_{sim}$ - mean uncorrected simulated precipitation,
$\bar{P}_{obs}$ - mean observed precipitation,
P - uncorrected simulated precipitation.

The bias correction factors were derived from the period of 2006 to 2018 and were applied for the year 2020 to 2100. The bias corrected RCMs output is reliable with historical data and was suitable for climate hazards studies. The reliability assessment was then conducted as discussed in section 3.3. To obtain a monthly precipitation threshold for flood event, the total of monthly precipitation intensity with an occurrence of flash flood event throughout the 19 years period, 2000-2018 were averaged in this study. Flood reports provided the information on the flood events occurred in districts of Langat River Basin including Hulu Langat, Kuala Langat, Sepang and Seremban. The

precipitation threshold for a flood event can be calculated from the average of precipitation intensity for flood events. By using the Equation (2), the flood risk can be calculated using the projected precipitation intensity and flood-precipitation threshold. If the value is less than 1.0, there will be no flood event occurring in that month. However, flood event may occur in a projected month if the value is equal or more than 1.0.

$$Flood\ Risk\ Assessment = \frac{Projected\ Precipitation\ [\mathrm{mm}]}{Flood{-}Precipitation\ Threshold\ [\mathrm{mm}]}\ . \quad (2)$$

According to the Department of Irrigation and Drainage Malaysia flood and drought reports, if a dam level falls below the alert level for two months consecutively, a drought event would be considered [17]. The months at which the storage level of Langat Dam was below the alert level were extracted from the drought report. The description of dam level based on balance storage is shown in Table 3.

Table 3: Description of dam level based on balance storage.

Dam level	Balance storage [%]
Maximum	Above 100
Normal	Between 100 to 70
Alert	Between 70 to 50
Warning	Between 50 to 40
Danger	Below 40

The drought report and standardized precipitation index (SPI) based on the months where drought events were recorded provided the monthly precipitation data. By averaging the monthly precipitation intensity over the number of events, the monthly precipitation threshold for drought event was obtained. With the drought precipitation threshold, it is possible to predict future occurrence of drought in the chosen RCP scenario. By using the Equation (3), the drought risk can be determined using the projected monthly precipitation and drought-precipitation intensity threshold. Assuming that a drought event will be occurred in that projected month if the value is less than 1.0; there will be no drought event will occur in the month if the value is equal or more than 1.0.

$$Drought\ Risk\ Assessment = \frac{Projected\ Monthly\ Precipitation\ [\mathrm{mm}]}{Drought{-}Precipitation\ Intensity\ Threshold\ [\mathrm{mm}]}\ . \quad (3)$$

The interpretation threshold of SPI based on Bhalme and Mooley [23]:

- > 2 - extremely wet,
- 1.5 to 1.99 - very wet,
- 1.0 to 1.49 - moderately wet,
- 0.99 to -0.99 - near normal,
- - 1.0 to -1.49 - moderately dry,
- - 1.5 to -1.99 - severely dry,
- > - 2.0 - extremely dry.

3.3 Reliability assessment

A total of four RCMs refer as CanESM2 RCP 4.5, CanESM2 RCP 8.5, ACCESS-CM2 RCP 4.5 and ACCESS-CM2 RCP 8.5 were applied for reliability assessment. To determine the relationship between observed precipitation data with four RCMs, the Pearson correlation (r), linear regression R^2 and probability density function (PDF) were used in this study. After plotting a scatter graph, a linear regression was applied to depict the degree of relationship [18]. The value of a variable based on the value of another variable was determined by applying the linear regression. Prabhakaran et al. reported that Linear regression models a continuous variable Y as a mathematical function of one X variable, this regression model can be used to determine the value of outcome variable, Y when only the value of predictor variable, X is known [19]. The mathematical equation is expressed as below:

$$Y = \beta_1 + \beta_2 X + \epsilon\ , \quad (4)$$

where β_1 and β_2 are the regression coefficients of the intercept and the slope, respectively. ϵ is an error value which belongs to Y that cannot be explained in the regression model. In this study, the dependent variable represents the RCM, and the independent variable represents the observed precipitation data. Linear regression was applied to analyze the accuracy of statistical downscaled climate model trend for the use of future prediction of climate hazards occurrence.

The probability density function (PDF) analysis was applied to determine the consistency between observation and RCMs data. The PDF is a function used to represent a continuous probability distribution. It was useful when handling probabilities of random variables that have continuous outcomes, such as precipitation intensity as in this study. It is based on Bayesian Theorem for distribution function which is used to determine the probability distribution when the number of outcomes is large. An example of a continuous probability distribution is the normal distribution where probability is represented by the area under the curve.

The normal distribution curve is generated by using the parameters such as mean and standard deviation of the historical precipitation data based on RCP 4.5 and 8.5 from 2006 to 2018. A similar probability outcome will be produced if the parameters between observed precipitation and local climate models (CMs) are similar. Subsequently, the RCP scenario which has the highest PDF curve that overlapped with the observed precipitation distribution curve will be chosen to project the local climate model for the period of 2020 – 2100.

4 Reliability of statistically downscaled climate model (CMs) for Langat River Basin

4.1 Pearson correlation and linear regression

The major outliers are successfully eliminated from the original dataset and the statistical analysis output was improved in this study. Table 4 shows the Pearson correlation coefficient, r and relationships of different CMs scenario with historical precipitation. The correlation coefficient was computed from monthly precipitation data. All CMs have been loaded with different correlation coefficient as 0.30 and 0.21. The correlation coefficient, r can be classified into $0.2 \leq |r|$ as weak relationship, $0.4 \leq |r|$ as moderate relationship, $0.6 \leq |r|$ as strong relationship, $0.8 \leq |r|$ as very strong relationship.

The ACCESS-CM2 RCP4.5 showed weak correlation with historical precipitation. Nevertheless, the CanESM2 RCP 4.5, CanESM2 RCP8.5 and ACCESS RCP 8.5 have been determined as moderate correlation. Apart from that, the linear regression, R^2, which measured the proportion of variation in the dependent variable, can be attributed to the independent variable. The result showed that all RCPs recorded a positive linear association with the observed precipitation. Based on the scatterplot of historical precipitation with CanESM2 RCP 4.5 in Fig. 2, it was considered reliable as it has relatively high correlation coefficient $r = 0.30$ among the CMs. The relationship between CMs and Langat River Basin historical precipitation are statistically significant $P < 0.05$. The results were verified using probability density function as shown in section 4.2.

Table 4: Pearson correlation, r of different local CMs with the observed precipitation from 2006 to June 2018.

RCMs	Scenario	Correlation coefficient r	Linear regression R^2	P-value
CanESM2	RCP 4.5	0.30	0.09	0.000212
CanESM2	RCP 8.5	0.21	0.05	0.008874
ACCESS-CM2	RCP 4.5	0.18	0.03	0.024013
ACCESS-CM2	RCP 8.5	0.29	0.05	0.000363

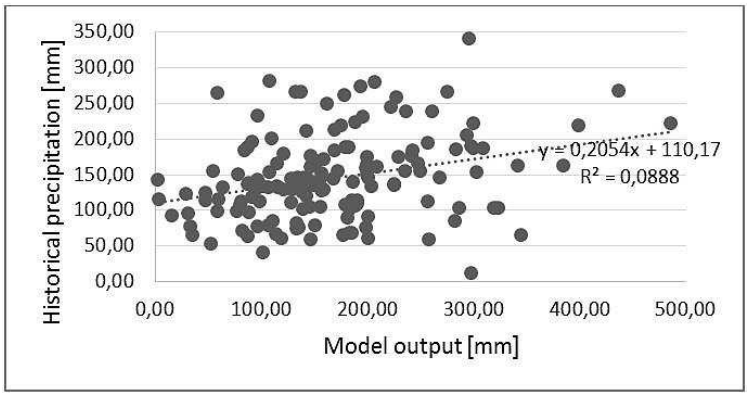


Fig. 2: Scatterplot analysis of historical precipitation (2006, 2018) data with CanESM2 RCP 4.5.

4.2 Probability density function (PDF) analysis

Probability density function (PDF) was performed to determine the consistency of CMs that have similar probability outcome as the historical precipitation 2006-2018. Similar probability outcome could be obtained if the parameters such as mean and standard deviation reading are closed. Based on Table 5, CanESM2 RCP 4.5, CanESM2 RCP 8.5 and ACCESS CM-2 RCP 4.5 scenario were recorded as similar mean and standard deviation with historical precipitation, except ACCESS2 RCP 8.5.

The percentage of overlapping of the observed precipitation and local CMs PDF curves indicates similarity of probability outcomes as shown in Fig. 3. The area under the curves was calculated using Wolfram Alpha website (wolframalpha.com). The equation of each PDF curve in Table 6 was determined using the formula below:

$$f(x) = ae^{-\frac{(x-b)^2}{2c^2}}, \tag{5}$$

where: *a* - maximum probability density function value, *b* - mean, *c* - standard deviation.

Table 5: Mean, $\bar{x}$ and standard deviation, σ of precipitation of observed, CanESM2 RCP 4.5, CanESM2 RCP 8.5, ACCESS CM-2 RCP 4.5, ACCESS CM-2 RCP 8.5.

Precipitation data	Mean $\bar{x}$	Standard deviation σ
Observed	169.45	86.47
CanESM2 RCP 4.5	144.52	59.58
CanESM2 RCP 8.5	139.46	63.02
ACCESS2 RCP 4.5	149.32	68.64
ACCESS2 RCP 8.5	1345.19	960.52

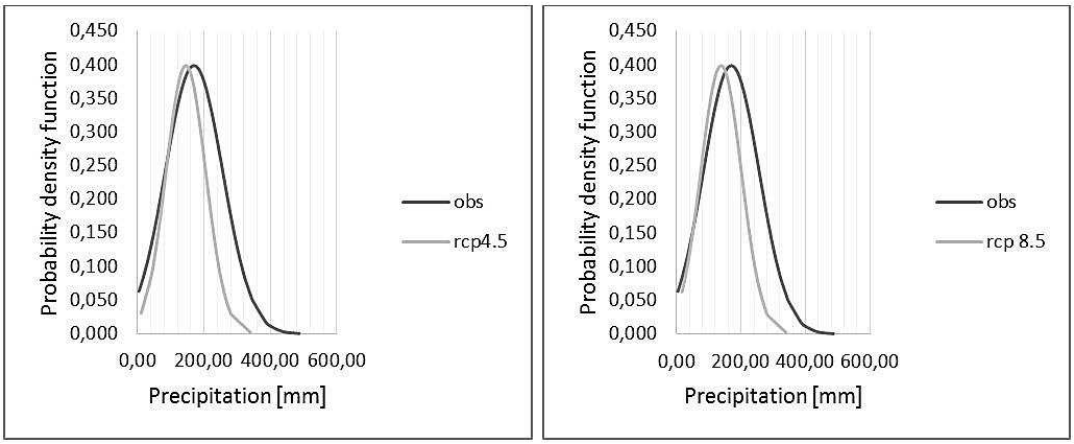


Fig. 3: Probability density function of observed (obs) with CanESM2 RCP 4.5 and 8.5 precipitation, 2006 - 2018.

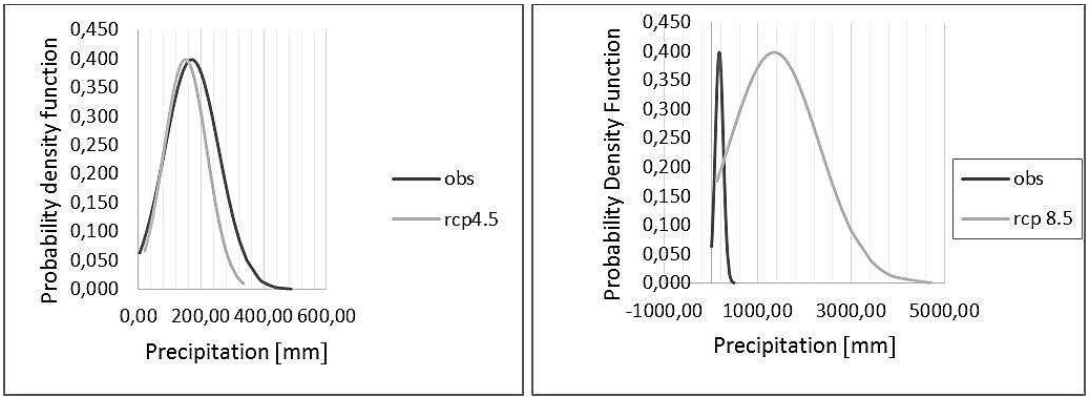


Fig. 4: Probability density function of observed (obs) with ACCESS CM-2 RCP 4.5 precipitation, 2006 - 2018.

Table 6: Exponential equation for different PDF curves.

PDF Curve	Equation
Observed precipitation	$f(x) = 0.40e^{-\frac{(x-169.45)^2}{2(86.47)^2}}$
CanESM2 RCP 4.5	$f(x) = 0.40e^{-\frac{(x-144,52)^2}{2(59.58)^2}}$
CanESM2 RCP 8.5	$f(x) = 0.40e^{-\frac{(x-139.46)^2}{2(63.02)^2}}$
ACCESS CM2 RCP 4.5	$f(x) = 0.40e^{-\frac{(x-149.32)^2}{2(68.64)^2}}$
ACCESS2 CM2 RCP 8.5	$f(x) = 0.40e^{-\frac{(x-1345.19)^2}{2(960.52)^2}}$

Analysis of difference between curves in PDF analysis is an useful technique and often applied in modeling field to determine if the simulation is accurately conducted based on historical trend. The results show the similarity of PDF curve for historical precipitation and CanESM2 RCP 4.5 (98.63 %); CanESM2 RCP 8.5 (98.01 %); ACCESS CM-2 RCP 4.5 (97.90 %) and ACCESSCM-2 RCP 8.5 (52.97 %). According to the Pearson correlation result, the CanESM2 RCP 4.5 has moderate correlation $r_{4.5}$ = 0.30. It indicates that the precipitation pattern for Langat River Basin is having similar trend with CanESM2 RCP 4.5 for 2006 - 2018. However, there was significant outlier detected for ACCESS CM-2 RCP 8.4. It may be due to excessive of mean precipitation that was downscaled in this study. According to Kuhlbrodt et al., the excess mean precipitation is a common error in different global atmospheric models [20]. The issue of double intertropical convergence zone (ITCZ) in the Pacific Ocean simulates excessive precipitation, and this error is observed in ACCESS2 model [21].

In the explanation of scenario emissions for RCP 4.5, anthropogenic activities such as agriculture, energy extraction, waste from landfills, aviation and surface transportation in Asian countries are accountable for majority of methane emission, increasing to maximum threshold in 2040, then decrease steadily through the rest of the century until about 13 % less emissions than in 2010. The climate model for Langat River Basin following RCP 4.5 scenario is consistent with the increasing efforts of Malaysia to reduce carbon footprint.

4.3 Flood and drought hazard threshold

Based on the flood reports from 2000 to 2018, a total of 208 flood events were recorded in the Langat River Basin. The flood events were sorted based on five regions to obtain monthly flood precipitation threshold for each region. The highest flood events were recorded 108 events in Hulu Langat District which located at the Central and Northern regions of the study area. As hydrological flood event was caused by heavy rain, only the events with precipitation >10.0 mm/hour were used to determine the monthly precipitation thresholds. Daily precipitation for each flood event was extracted and downscaled using temporal distribution approach to obtain the precipitation intensity [mm/hour]. Hence, the determined monthly precipitation thresholds for flood occurrence will only be included for heavy rain events or worse were considered in this study. Table 7 shows the average monthly precipitation for any flood events occurred with intensity > 10 mm/hour. The thresholds were computed using the flood data record from year 2000 to 2018. Then, it was analyzed with chosen climate model to predict the likelihood of flood occurrence 2020 - 2100 for Langat River Basin as discussed in next section.

Table 7: Average monthly precipitation intensity for flood occurrence.

Region	Monthly precipitation intensity for flood occurrence (>10.0 mm/hour)
Central	168.5 ± 60.8
Northern	168.5 ± 60.8
Southern	173.2 ± 42.9
Western	208.8 ± 56.6
Eastern	120.5 ± 31.3

For the drought risk assessment, a total of five drought events in 2000 - 2018 were recorded in Langat River Basin. The storage level, SPI-1 and SPI-3 of Langat River Basin was determined as shown in Table 8. The events recorded in the drought reports were based on hydrological drought definition. A hydrological drought event is defined when a dam level falls below 50 % [17]. The storage level was recorded as lowest as 39.67 % on 15th September 2015. However, it was observed that during the hydrological drought events, the monthly precipitation intensities were recorded as 186.5 mm in the study area. Apart from that, based on SPI-1 and SPI-3, the climate conditions were observed as moderately wet, near normal and extremely dry. This may be due to hydrological drought events which are only observable after meteorological droughts occurrence. Meteorological drought events occurred when dry weather pattern or low precipitation dominates an area [22]. For example, when the hydrological drought event occurred in October - December 2015, the SPI-3 drought intensity was still recorded as near normal. Nevertheless, there was a moderately and extremely dry characteristic recorded in July and October 2015 based on in meteorological drought event as shown in Table 9. This indicates that there is sufficient time for the water reservoir level to drop to warning level < 50 %, thus the hydrological drought occurrence in Langat River Basin.

Preliminary drought threshold was determined by averaging the monthly precipitation during the hydrological drought events. The preliminary drought threshold obtained for Langat River Basin as 203.4 mm which unreasonable as in projected precipitation by CanESM2 RCP 4.5, most of the monthly precipitation was recorded as lower than 200.0 mm. This suggests a very frequent drought in time ahead for Langat River Basin if preliminary threshold was used.

As discussed earlier, it was observed that the reduction of dam storage level would require time to fall below alert level and to be classified as a hydrological drought event in Langat River Basin. It is feasible to determine the precipitation intensity threshold using the meteorological drought event information i.e. The monthly precipitation with SPI-1 and SPI-3 value less than -1.0 (moderately dry). The monthly precipitation meteorological drought events were used to re-calculate the precipitation intensity threshold. The monthly precipitation intensity threshold was re-calculated to be 20.5 ± 23.7 mm/month.

Table 8: Hydrological drought events in Langat River Basin according to dam level 2000 - 2018.

Month and year of drought events	Monthly precipitation [mm]	Storage level [%]	SPI-1	SPI-1 Drought intensity	SPI-3	SPI-3 Drought intensity
March 2014	316.5	49.0	1.06	Moderately wet	- 0.42	Near normal
September 2015	186.5	39.7	0.20	Near normal	- 0.09	Near normal
October 2015	21.0	39.1	- 2.12	Extremely dry	- 0.27	Near normal
November 2015	327.1	49.2	1.12	Moderately wet	- 0.01	Near normal
December 2015	166.0	49.2	0.32	Near normal	0.05	Near normal

Table 9: Meteorological drought events used to determine the drought threshold 1998 - 2018.

Month and year of drought events	Monthly precipitation [mm]	SPI-1 value	SPI-1 Drought intensity	SPI-3 value	SPI-3 Drought intensity
August 1998	2.0	- 2.59	Extremely dry	- 0.96	Near normal
September 1998	0	- 2.59	Extremely dry	- 2.59	Near normal
February 2014	23.0	- 2.04	Extremely dry	- 1.08	Moderately dry
July 2015	58.9	- 1.23	Moderately dry	- 1.09	Moderately dry
October 2015	20.5	- 2.12	Extremely dry	- 0.27	Near normal

4.4 Climate hazard risk prediction

The determined monthly precipitation intensity thresholds for drought and flood event were applied to predict future flood and drought risk using Equation (2) and (3). The statistically downscaled CanESM2 RCP 4.5 scenario was chosen to predict climate hazard risk for 2020 - 2100 period. Precipitation threshold for drought 20.5 ± 23.7 mm/month and flood 168.5 ± 60.8 mm/month were determined for central and northern region of Langat River Basin. Due to flood pattern found differently in southern and western region, the precipitation thresholds for flood risk were determined which were 173.2 ± 42.9 mm/month and 208.83 ± 56.6 mm/month. It may be due to low urbanization rate and high forested land in southern and western region, the precipitation thresholds are determined slightly higher compared to central and northern region of Langat River Basin.

As shown in Fig. 5 and 6, it shows the projected precipitation in different regions of local monthly precipitation intensity (mm/month) when flood and drought threshold applied. As drought was determined by dam water level, the monthly precipitation intensity threshold for drought risk is only applied to Central and Northern regions where the Langat dam is located at the study area. There are two potential drought events that is February 2069 and February 2099 occurred in Central region. The extreme dry condition is predicted to be 16.5 mm/month, 6.1 mm/month. The outcome is consistent with the study conducted by Ang [13] that there will be no frequent severe drought is expected to occur in Langat River Basin for the period of 2020 to 2100.

The flood occurrence rate for central, northern, southern, western, and eastern region in Langat River Basin are determined as 41.97 %, 60.19 %, 40.23 %, 20.16 %, and 34.98 % respectively. It was derived from the number of months that exceeded the monthly precipitation threshold >1.0 in Fig. 5-8. It was consistent with the observed information and climate hazard occurrence rate. Higher flood occurrence rate at Central and Northern regions was mostly due to greater urban area and deforestation activity compared to the other regions.

There are rapid development activities in the Central and Northern regions of Langat River Basin including human settlements, factories and transportation. These activities emitted high levels of GHGs thus contributing higher temperature. Warmer atmosphere increases evaporation, leading to greater humidity and greater average precipitation. This explained that Central and Northern regions would have higher frequency of flood events as compared to other regions. The predicted climate hazard occurrence rate was also observed to increase significantly from the observed occurrence rate. Based on RCP 4.5 scenario, as the predicted GHGs concentration increases to 421 ppm and climate forcing of 4.5 W/m^2 in 2100, more heat will be absorbed and trapped in lower atmosphere causing climate change, higher frequency of precipitation irregularities and occurrence of climate hazards.

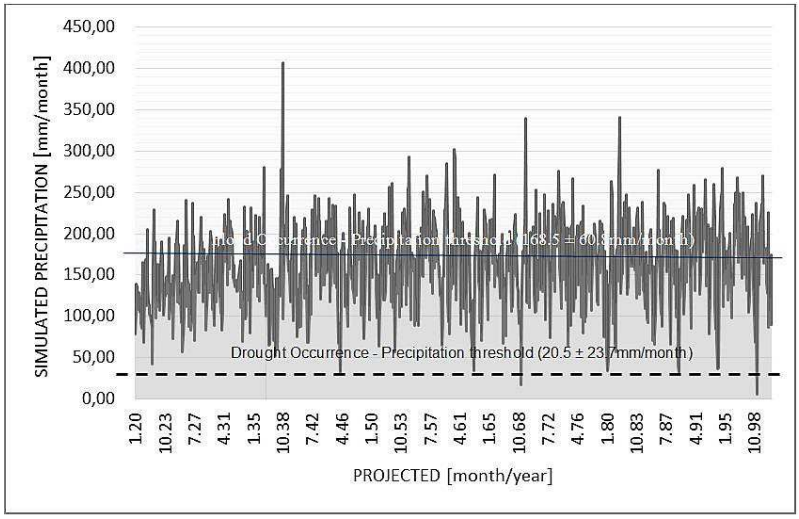


Fig. 5: CanESM2 RCP 4.5 scenario precipitation [mm/month] 2020 to 2100 for central region, Langat River Basin. Precipitation threshold [mm/month] for drought: 20.5 ± 23.7 mm/month; and flood: 168.5 ± 60.8 mm/month.

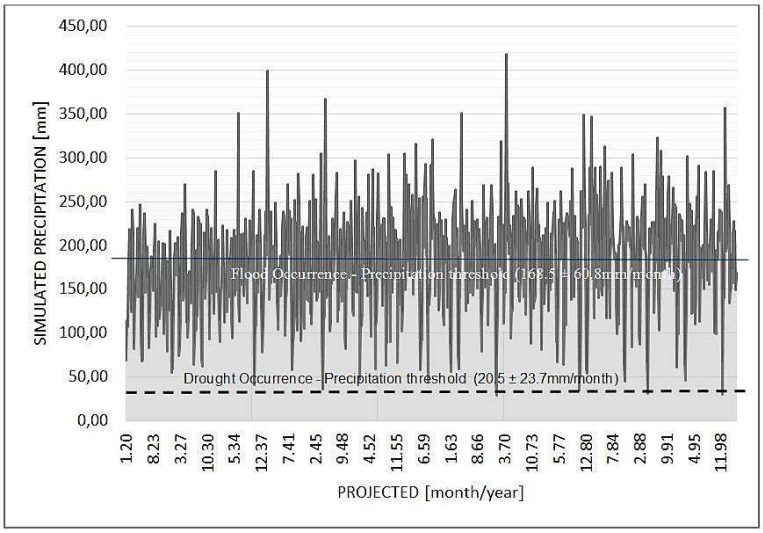


Fig. 6: CanESM2 RCP 4.5 scenario precipitation [mm/month] 2020 to 2100 for northern region, Langat River Basin. Precipitation threshold [mm/month] for drought: 20.5 ± 23.7 mm/month; and flood: 168.5 ± 60.8 mm.

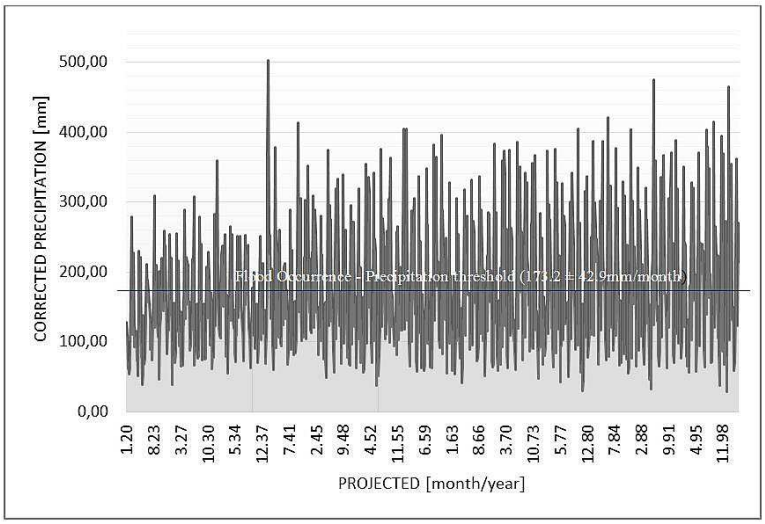


Fig. 7: CanESM2 RCP 4.5 scenario precipitation [mm/month] 2020 to 2100 for southern region, Langat River Basin. Precipitation threshold [mm/month] for flood: 173.2 ± 42.9 mm/month.

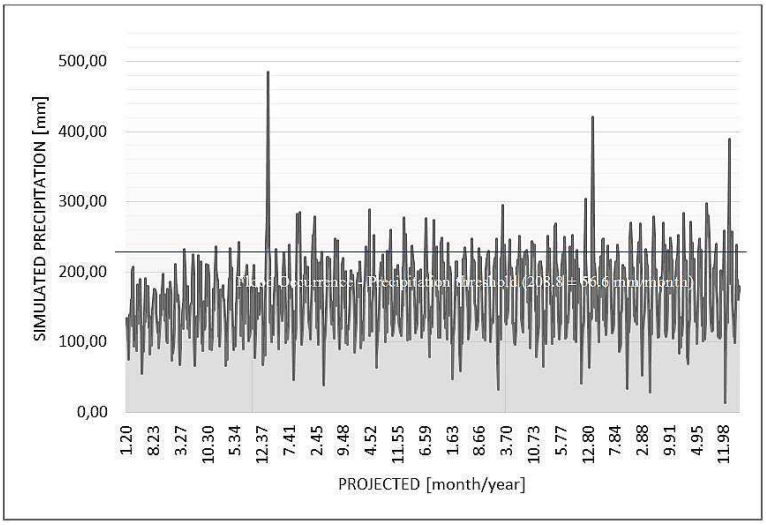


Fig. 8: CanESM2 RCP 4.5 scenario precipitation [mm/month] 2020 to 2100 for western region, Langat River Basin. Precipitation threshold [mm/month] for flood: 208.83 ± 56.6 mm/month.

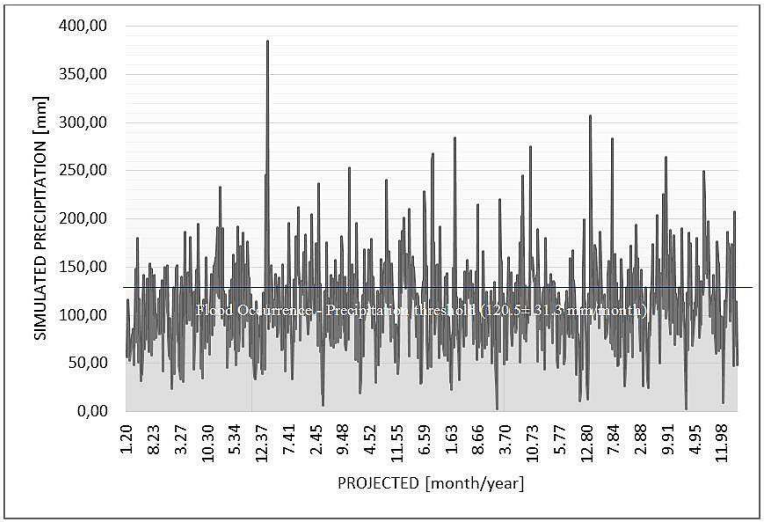


Fig. 9: CanESM2 RCP 4.5 scenario precipitation [mm/month] 2020 to 2100 for eastern region, Langat River Basin. Precipitation threshold [mm/month] for flood: 120.5 ± 31.3 mm/month.

5 Conclusion

This study demonstrates the application of local climate model (CM) in flood disaster and drought risk analysis. The likelihood of potential drought and flood risk for the period of 2020 to 2100 are predicted based on CanESM2 RCP 4.5 as well as the proposed precipitation intensity thresholds [mm/month]. A total of two drought events are likely to be occurred in central region of Langat River Basin. The Central and Northern regions of Langat River Basin are predicted to have highest flood risk occurrence rate at 41.97 % and 60.19 %, respectively. It is due to rapid urbanization and deforestation activity in the region. In order to predict the daily flood event accurately, the disaggregating of daily precipitation into hourly precipitation is suggested for further study. It was feasible to generate the local hourly precipitation model by using the Gumbel distribution and to find out the rain intensity duration frequency (IDF) for climate risk assessment for Langat River Basin.

Acknowledgements

We would like to thank the Malaysia Ministry of Higher Education for providing research funding –FRGS/1/2019/TK01/UTAR/02/1. We also like to thank the Malaysian Meteorological Department (MMD) and Department of Irrigation and Drainage (DID) for providing data and information to complete the climate modelling downscaling work.

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