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Rainfall Characteristics Over Kenyir Dam Catchment Under AR5 Climate Change Scenarios

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Abstract

In this study, the Coupled Model Intercomparison Project Phase 5 (CMIP5) dataset namely CanESM2, a Canadian Earth System Model was used to assess the potential changes of rainfall characteristics over the Kenyir dam catchment. The changes were computed for two future time slices (2025–2055 and 2056–2085) relative to the reference period (1988–2017) under three Representative Concentration Pathways (RCPs; RCP2.6, RCP4.5 and RCP8.5). For comparison purposes, climate change data was also obtained from National Hydraulic Research Institute of Malaysia (NAHRIM). NAHRIM climate data are based on GCMs adopting the Special Report on Emission Scenarios (SRE) scenarios in the AR4. The three selected GCMs were CCSM3, ECHAM5 and MRI-CGCM2.3.2. The simulated rainfall patterns generally resemble those in the historical observations. However, the CCSM, ECHAM and MRI produce lower monthly rainfall, while generally CanESM2 simulations produce monthly rainfall that are more consistent with the historical observations for RCP2.6, RCP4.5 and RCP8.5. The projected future climate rainfall by the CanESM2 suggest slightly decreasing of total rainfall over the Kenyir dam catchment due to the global warming. The largest decrement appears to be in January and February. The analysis of historical daily rainfall characteristic has suggested remarkable changes in the hydroclimatic regimes over this catchment. Understanding of such changes allow better risk assessment and mitigation planning for water security.

1. Introduction

Reports showed significant changes in both the intensity and variability of precipitation due to climate change and has become a key issue in water management all over the world [1], [2]. It is important to thoroughly assess the changes to develop robust adaptation strategies that can effectively mitigate the risks associated with extreme precipitation. Projecting future rainfall scenarios is one step toward addressing the issues posed by climate change. Global Climate Models (GCMs) are widely used to simulate climate dynamics on a global scale, standardized by the Coupled Model Intercomparison Project (CMIP) [3], [4]. GCMs are reliable tools for assessing climate evolution under various anthropogenic forcings, like greenhouse gas emissions, and estimating future climates based on different emission scenarios. They are based on physical principles that accurately recreate current and historical climate features. The impacts of climate change need to be reflected at regional or local scale to enhance planning, development and management for a climate-resilient future. However, GCMs have typical resolution of 100-300 km and thus cannot resolve local processes, such as orographic forcings, coastal processes, local convection and land-sea breeze etc., that are crucial for local precipitation formation. Hence, further downscaling is required to rectify this misrepresentation. Downscaling can allow a coarse spatial resolution from GCMs into a fine spatial resolution for watershed modelling.

Over the past two decades, Malaysia has seen irregularities in rainfall, garnering much research attention in the study of climate trends [5], [6]. Othman and Tukimat [7] assessed climate prediction over Hulu Terengganu, Malaysia using CMIP6 (based on Shared Socioeconomic Pathways, SSPs). SSPs scenarios showed a declining trend in projected rainfall, with SSP1-2.6 producing the largest declining trend magnitude. The annual rainfall for SSP2-4.5 and SSP5-8.5 only began to decrease in 2070-2099 (Δ2080). The effects of climate change on the Northeast monsoon (NEM) season in Peninsular Malaysia have become increasingly evident. Firstly, changes in rainfall patterns in terms of intensity and distribution of rainfall have been observed [8]. Maturidi et al. [9] in their study found a shift towards more intense rainfall events during the NEM season, increasing the risk of flooding and landslides. Sa'adi et al. [10] concluded that NEM season rainfall patterns showed consistent increases in certain climate zones during the mid-future (2021–2060) period. However, in the far-future (2061–2100), the Southeast zone saw an overall increase in rainfall. Meanwhile, the Central-West zone showed mixed results, and the Northeast zone exhibited varied patterns of change. There is still a lack of catchment-scale studies documenting trend and changes in rainfall due to climate change in Malaysia [11]. Therefore, the current study attempts to highlight the latest projections of rainfall in the Kenyir Dam catchment.

2. Methodology

2.1 Study Area and Data

Kenyir Dam commands a catchment area of 2,612 km^2, which is about half the size of the Sg Terengganu River basin with area of 4596 km^2 as shown in Fig. 1. The Kenyir Dam is located about 50 km south-west of Kuala Terengganu on the east coast of Peninsular Malaysia. The length of Sg Terengganu is about 50 km from the Kenyir Dam to the river mouth. The Kenyir Dam catchment area consists of undulating hills and mountainous terrain with elevations ranging from 160 to 1,519 mRL. The highest point is Gunung Lawit along the northern boundary of the study area with elevation of 1,519 mRL. Foundation rock at the main dam is sound granite with igneous intrusions. The land use is predominantly natural forest and water body.

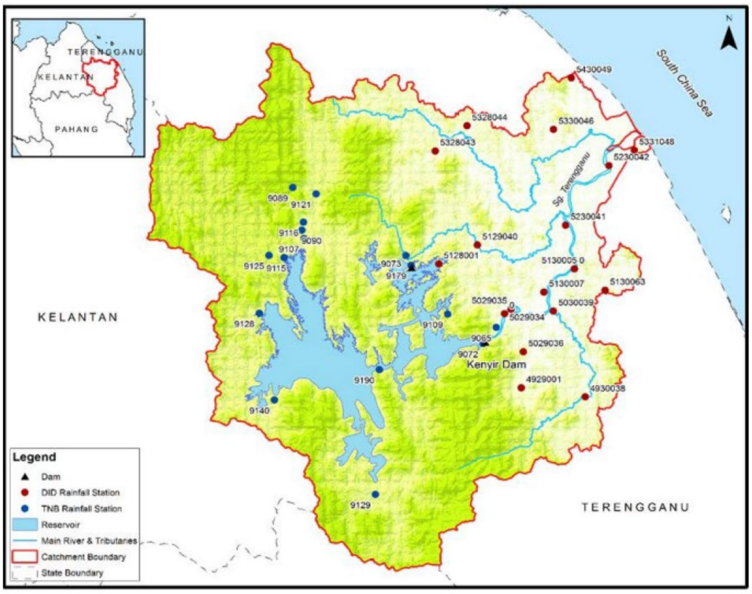


Fig. 1 *Location map of the study area (Source: TNB Report)*

2.2 Rainfall and Climate Data

There are a total of 27 active Department of Irrigation and Drainage (DID) rainfall stations (Fig. 1) located around the Kenyir Dam catchment. Most of the DID stations have long historical records, ranging from 32 years to 82 years. In addition to the DID stations, TNB operates 17 rainfall stations located within the Kenyir dam catchment. For this study, a total of 10 rainfall stations, as shown in Table 1, were selected as the point for the downscaling of the future climate change rainfall data. The observed data from the stations were also used for bias correction of the downscaled future climate data over the historical period. The criteria for selection of the station were the data availability.

Table 1 *Selected rainfall stations for climate projection*

No.	Station Name	Data Availability
1	Kg. Embong Sekayu	1975 – Sept 2021
2	Kg. Dura	1966 – Oct 2021
3	Sg. Gawi	1983 – Oct 2021
4	Kajiklim Kenyir	1979 – Oct 2021
5	Empangan Pelana F (Kenyir)	1988 – Oct 2021
6	Sg. Tembat	1986 – Oct 2021
7	Sg. Petuang	1990 – Oct 2021
8	Sg. Ketiar	1993 – Oct 2021
9	Sg. Terengganu	1994 – Oct 2021
10	Ulu Sg. Kerbat	1994 – Oct 2021

2.3 Missing Data Treatment using Inverse Distance Weighted (IDW)

The selection of rainfall stations was based on the data quality which refers to less than 10% of missing data with the maximum data loss of less than seven (7) consecutive months. Before conducting the climate analysis, all missing data must be addressed and treated to provide complete, homogeneous, and reliable data before performing the climatic analysis. When dealing with long time projection analysis, the accurate estimation in missing data analysis is a challenging problem that necessitates particular cares. Missing data from these rainfall stations were gap-filled using the data from the neighbouring stations to produce complete datasets. One of the most well-known and widely used method especially when dealing with the large scale of missing data is the Inverse Distance Weighted (IDW). Equation (1) is the formula for IDW method.

$$V_o = \frac{\sum_{i=1}^{n} \left({}^{V_i}/_{D_i} \right)}{\sum_{i=1}^{n} \left({}^{1}/_{D_i} \right)} \tag{1}$$

where V_o is the assessed value of the missing data, V_i is the value of same parameter at i^{th} nearest station, D_i is the distance between the station with missing data and the i^{th} nearest station.

2.4 Statistical Downscaling Method

In this study, the climate change data used was obtained from the downscaling of the General Circulation Models (GCM) namely CanESM2, the Canadian Earth System Model from the Coupled Model Inter-comparison Project Phase 5 (CMIP5). The scenarios adopted were based on the three RCPs namely, RCP2.6, 4.5 and 8.5 in the AR5. The RCP scenarios are denoted by the approximate level of radiative forcing (W/m2) with respect to the pre-industrial periods that can potentially be reached by the year 2100, and describes alternative trajectories of greenhouse gas concentrations. The detail descriptions pertaining to each RCP scenario can be found in the IPCC report [2]. For the analysis, the data were downloaded from *https://esgfnode.llnl.gov/projects/ cmip5/.* In addition to that, the climate change data was also obtained from National Hydraulic Research Institute of Malaysia (NAHRIM) for comparison purposes. NAHRIM climate data are based on GCMs adopting the SRES scenarios in the AR4. The SRES provides four narrative storylines through which the future development in the global environment can take place and relates these narratives to the production of greenhouse gases and aerosol precursor emissions during the 21st century. Future rainfall data comprises from three selected NAHRIM GCMs namely (i) CCSM3 (National Centre for Atmospheric Research (NCAR) of the United States), (ii) ECHAM5 (Max Planck Institute of Meteorology of Germany) and (iii) MRI-CGCM 2.3.2 (Meteorological Research Institute of Japan) were used for comparison.

For comparable comparison between the GCMs adopting the RCPs of AR5 (adopted in this study) and SRES of AR4 (adopted by GCMs of NAHRIM), the SRES scenario can be related to the RCP scenarios. In terms of the overall forcing, SRES A2/A1F1 scenarios in AR4 are comparable to RCP8.5 in AR5. Furthermore, SRES B2 scenario is comparable with RCP6.0 and SRES B1 is comparable with RCP4.5. However, there exists no SRES scenario that can be comparable to the RCP2.6 scenario.

2.5 Bias Correction using Linear Scaling Model

Daily rainfall simulated by the selected CMIP5 GCMs was provided on coarse grids. These statistical downscaled future climate change data require a bias correction to remove the biases between the downscaled with the observed data. In this study, linear scaling model was used. The bias correction was carried out using the historical dataset generated from the downscaled GCMs model and the observed data from the selected ground stations. This results in more consistent values with the observation over the historical period. The bias correction was applied on each of the 12 months rainfall data with separate calibration for each station. The linear scaling model equation is given as follows:

$$BC = \frac{P_{obs(avg)}}{P_{sim(avg)}} \quad (2)$$

$$P'_{sim} = P_{sim(i)} \times BC \quad (3)$$

where P_{obs} refers to average of monthly observed rainfall, P_{sim} refers to average of monthly rainfall from all the selected models. The simulated rainfall was determined from 30 years of data (1985-2014).

3. Results and Discussion

3.1 Future Changes of Rainfall using Statistical Downscaling

In this study, the CMIP5 dataset was used to examine the potential changes of rainfall characteristics over the Kenyir dam catchment. The changes were computed for two future time slices (2025–2055 and 2056–2085) relative to the reference period (1988–2017) under three Representative Concentration Pathways (RCPs; RCP2.6, RCP4.5 and RCP8.5). CanESM2 simulated daily precipitation and temperature were downscaled to a finer resolution following the observed station locations. A total of 10 stations were selected for rainfall projection. The results were then compared using the data provided by NAHRIM (based on Special Report on Emissions Scenarios (SRES)) namely CCSM, ECHM and MRI. Although the scenarios used by NAHRIM are from the older emission reports, the comparison can still provide some general guidelines.

The performances of the CanESM2, CCSM, ECHM and MRI were first examined. Fig. 2 compares the monthly rainfall between the historical (1988–2017) and the CanESM2 ensemble (2015–2020), and CCSM, ECHM and MRI (1988–1999). It is noted that the simulated rainfall and patterns generally resemble those in the observations. However, the CCSM, ECHM and MRI produced lower monthly rainfall, which generally the climate model simulations produce much higher monthly rainfall. The analysis of historical daily rainfall characteristic has suggested remarkable changes in the hydroclimatic regimes over this catchment. Understanding of such changes allow better risk assessment and mitigation planning for water security.

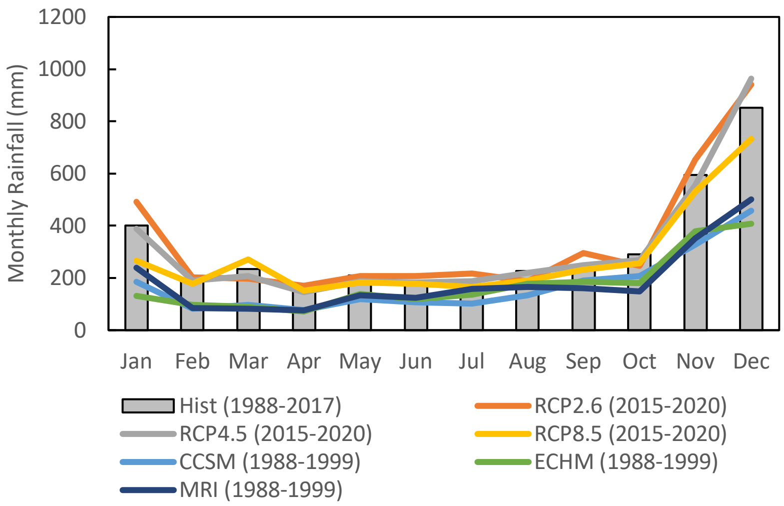


Fig. 2 *Comparison of monthly simulated rainfall between historical (1988–2017) with GCM-CanesM2 (2015–2020), CCSM (1988–1999), ECHM (1988–1999) and MRI (1988–1999)*

Fig. 3 depicts the rainfall projection for all 10 stations using CanEMS2 under RCP2.6, RCP4.5, and RCP8.5 for the period 2050–2085. The annual rainfall was found to increase more under RCP8.5 in comparison with other RCPs. These findings are consistent with the study by Othman & Tukimat [7], which found that the trend of future rainfall in Terengganu is increasing. For calculating the changes in annual projected rainfall, the projected annual rainfall was compared with the annual average rainfall for the historical period. Fig. 4 shows the mean changes in annual rainfall for the 2025–2055 and 2056–2085 futures with reference to the 1988–2017 period under the three RCPs scenarios.

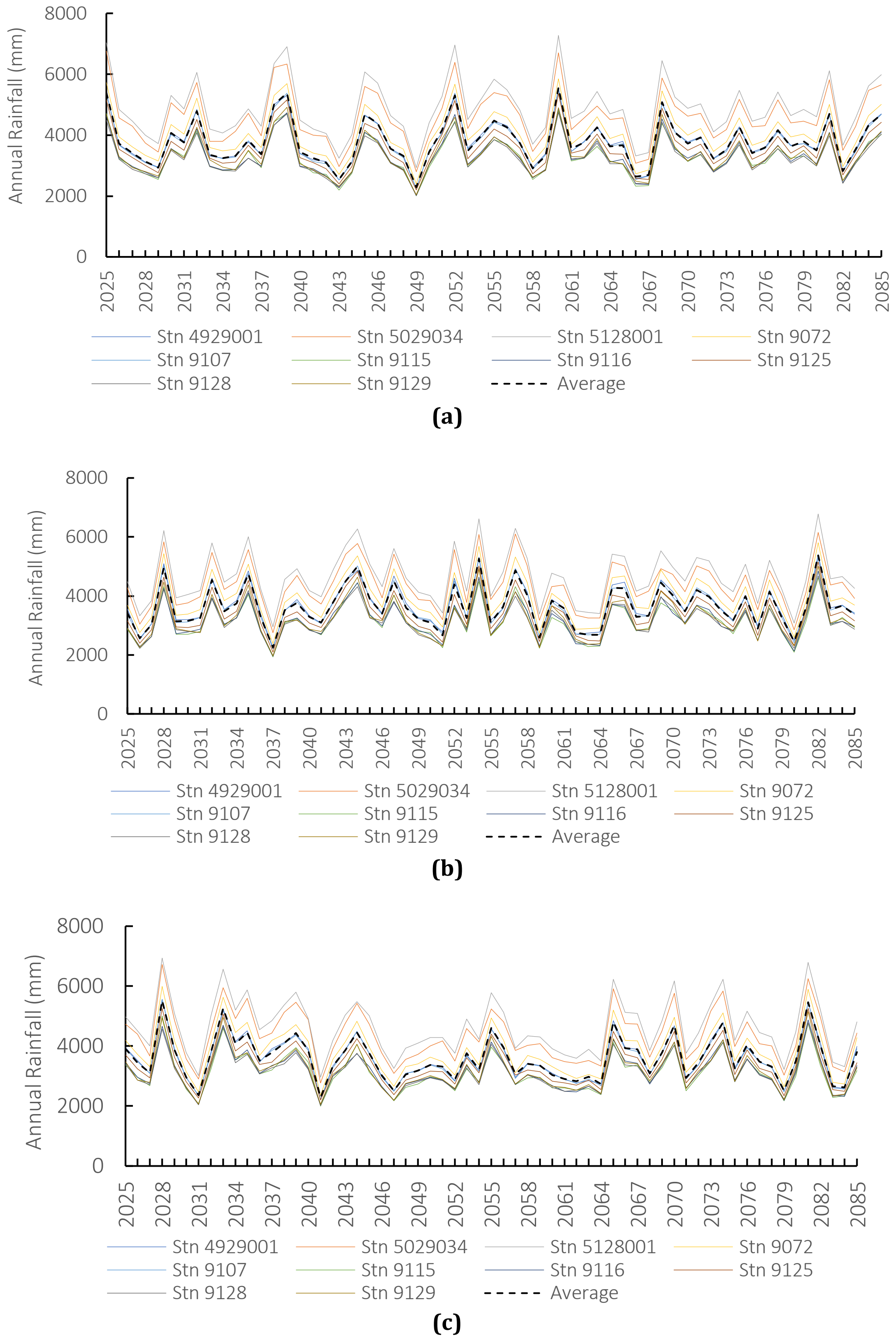
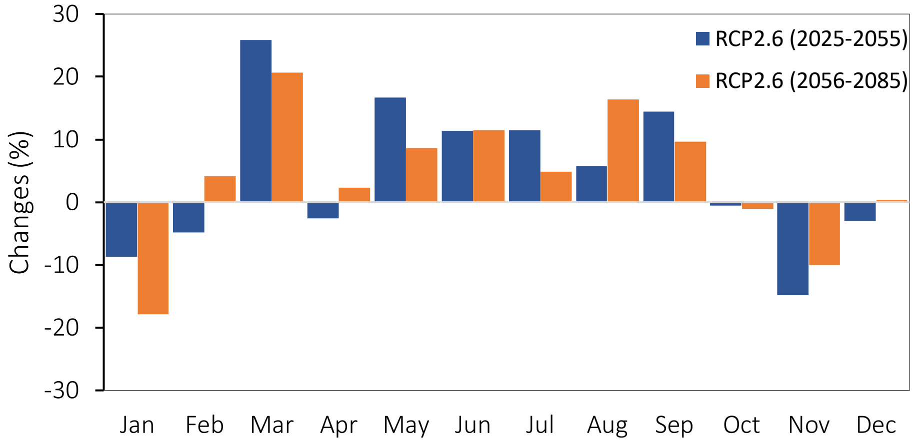


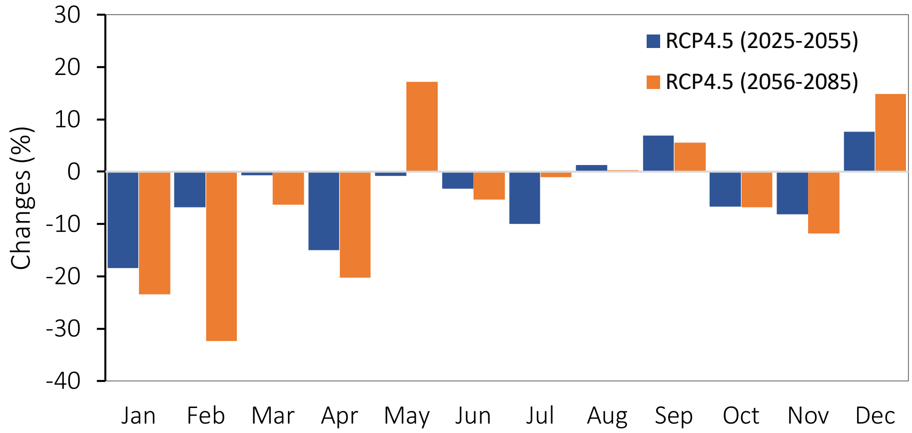
Fig. 3 *Time series of the projected annual rainfall (2025 to 2085) by GCM-CaESM2 driven by (a) RCP2.6; (b) RCP4.5; and (c) RCP8.5 scenarios*

Based on Fig. 3(a) under RCP2.6, it was found that for the first 30 years' period 2025–2055, the rainfall increment is projected up to 26% in March compared to the historical period. While for 2056–2085, downscaled projection suggests the rainfall may reduce by 1-18% compared to the current climatology in October, November and January. The projections of RCP4.5 for both periods 2025–2055 and 2056–2085 in Kenyir dam catchment are slightly different (see Fig. 3(b)). The rainfall is projected to decrease in the first half of the year by 1–33%. For the second half of the year, the rainfall increments in December are projected to exceed 8% and 15%, respectively compared to the historical period.

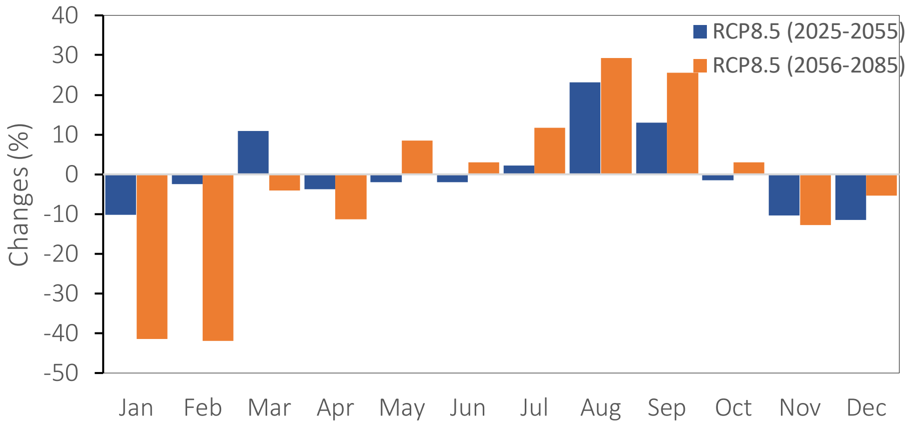
The projection of RCP8.5 for period 2056–2085 suggests decrement for the first four months (Jan – April), where the rainfall may reduce by 4–42% compared to the current climatology (Fig. 3(c)). This is slightly like RCP4.5. The largest reduction is projected to occur in February. Although the rainfall reduction signal is not particularly clear during the 2025-2055 period, its projected reduction is remarkable at the second 30 years' period 2056–2085.



(a)



(b)



(c)

Fig. 4 *The average changes of the future monthly rainfall as projected by the CanEMS2 driven by (a) RCP2.6, (b) RCP4.5 and (c) RCP8.5 for 2025–2055 and 2056–2085*

Fig. 5 depicts the time series of the downscaled projected annual total rainfall from the ensemble of CanESM2 (RCP2.6, RCP4.5, and RCP8.5), CCSM3 (A1F1, A2, B1 – NAHRIM), ECHM5 (A2 and B1 – NAHRIM) and MRIB1 (NAHRIM). Fig. 6 shows the downscaled catchment rainfall climatology comparison between the historical period and the future period of 2025-2055 and 2056-2085.

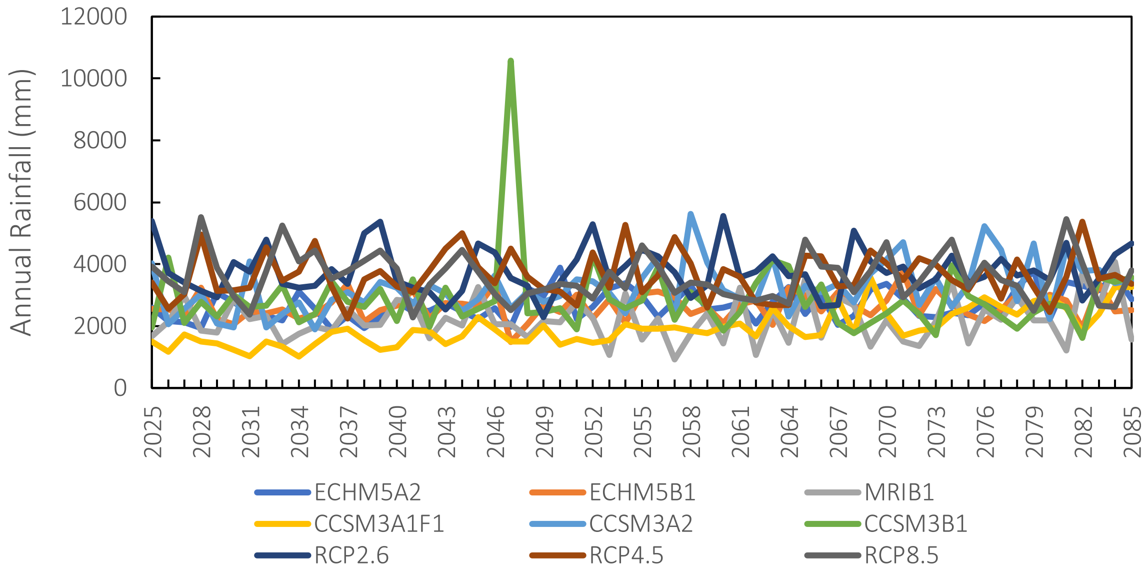
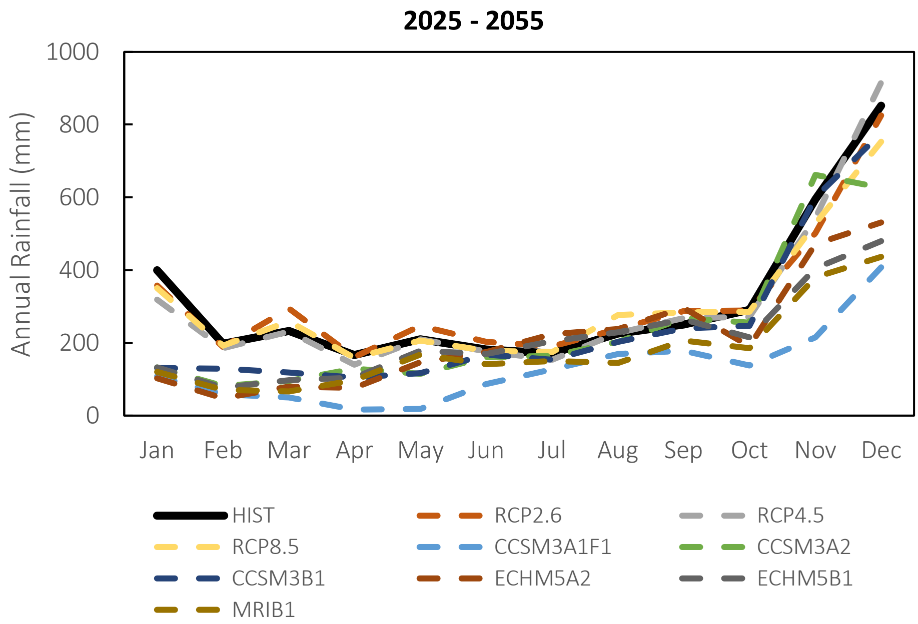
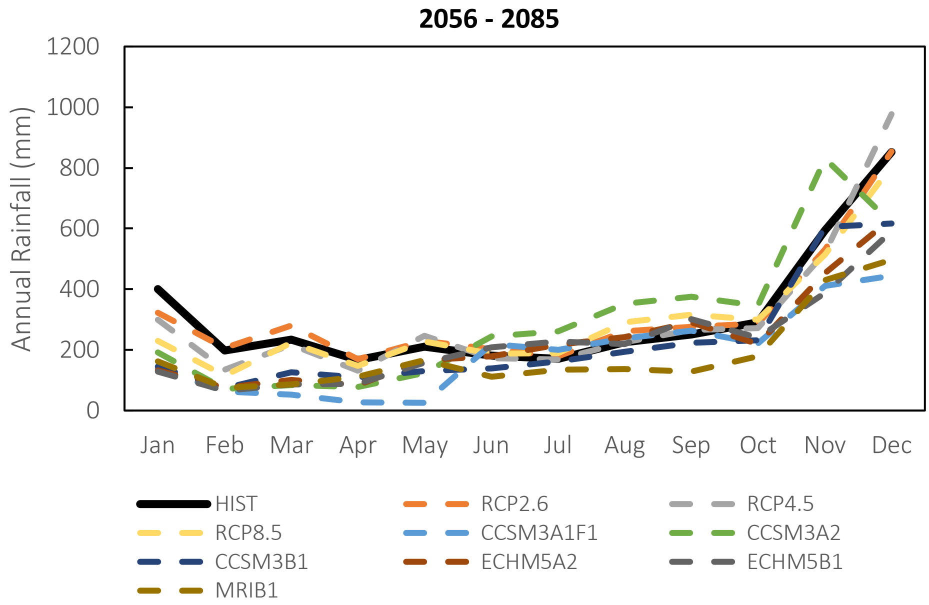


Fig. 5 *Comparison projected annual rainfall (2025-2085) between CanESM2, CCSM3A1F1, CCSM3A2, CCSM3B1, ECHAM5A2, ECHAM5B, and MRIB1*



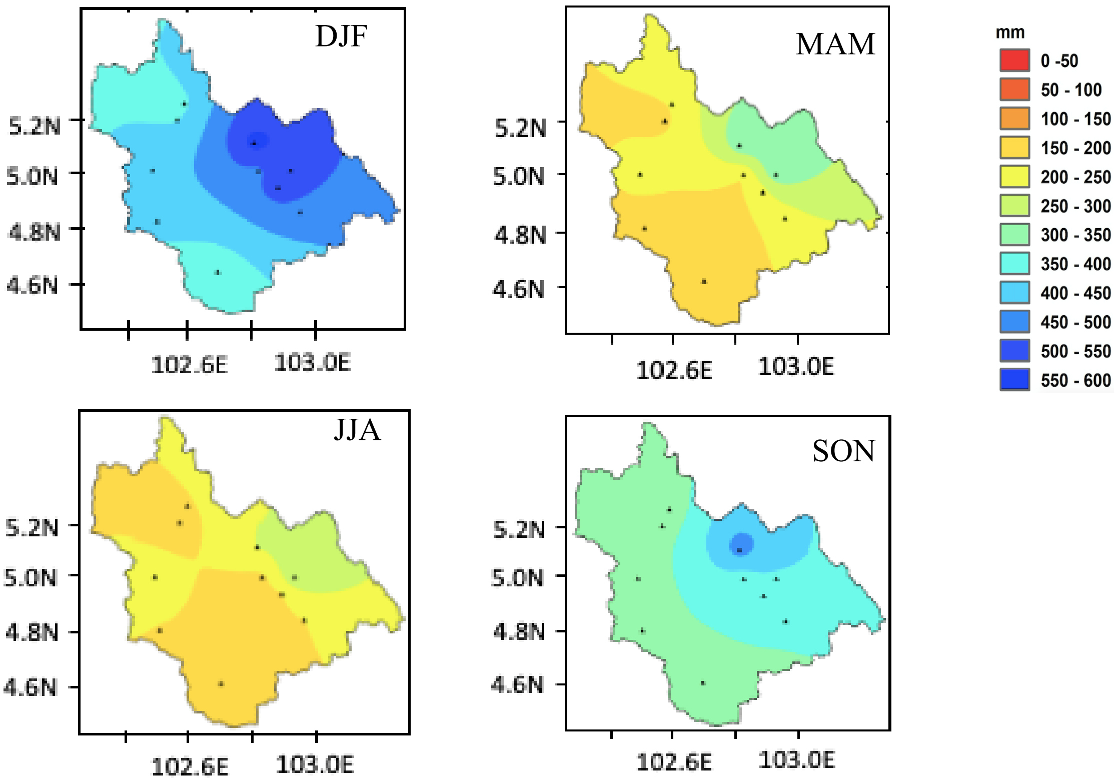
(a)



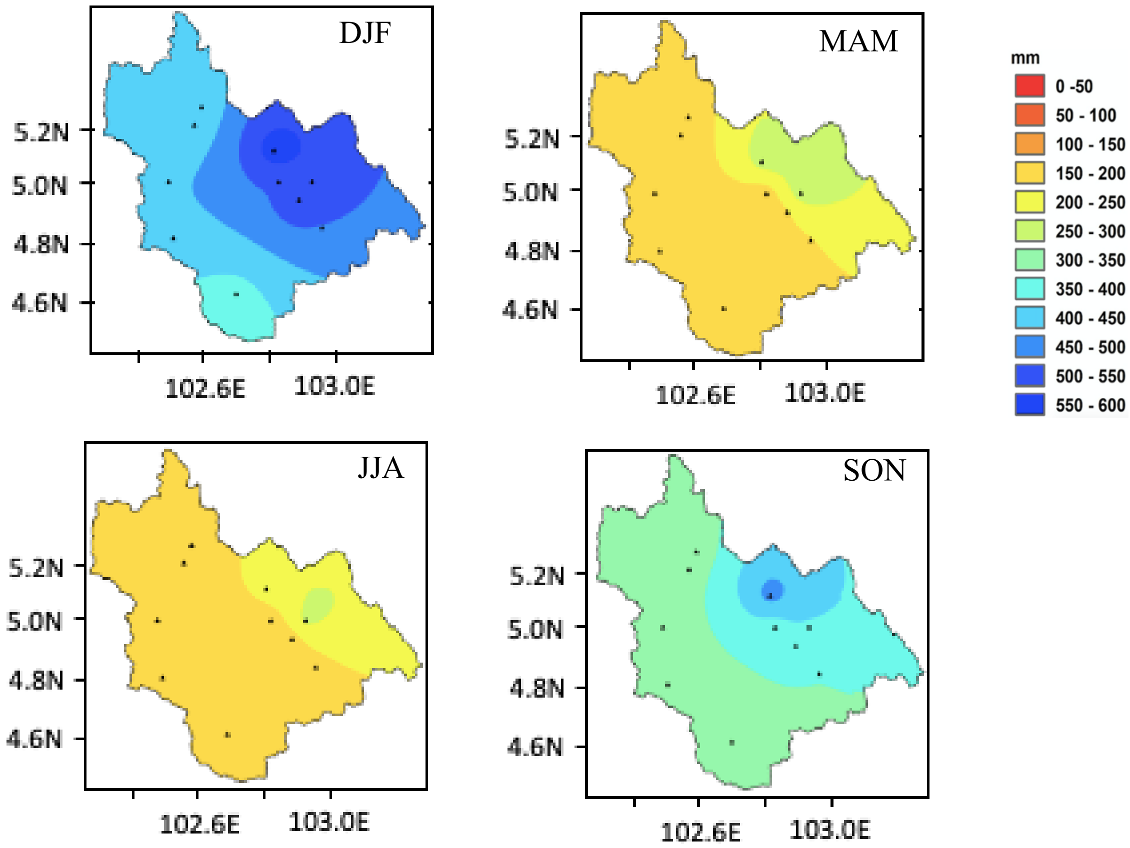
(b)

Fig. 6 *The annual cycle of the monthly historical rainfall and the future period as simulated by the 7 GCMs. (a) Future annual cycle over 2025–2055; (b) Future annual cycle over 2056–2085*

To visualize the spatial variations of the annual rainfall, the projected values according to seasons are mapped. Fig. 7 shows annual rainfall 2025–2085 for Dec–Feb (DJF), Mar–May (MAM), June–Aug (JJA) and Sep–Nov (SON) for all RCPs. The values show considerable spatial variations. During MAM when the projection generally shows a significant reduction in the total rainfall, the area which shows the largest reduction appear to be located over the northern halve of the catchment. This is associated to largest reduction of rain day frequency over the same area. However, the largest increment in the dry spell appears to be over the south as well as northeastern part of the catchment. During JJA when the projection estimated an increment in total rainfall, the signal is stronger over the eastern part of the catchment, where the amount may exceed 25% compared to the historical period. This is associated to the increasing rainfall intensity over the same areas. Generally, the climate change for RCP8.5 shows considerable spatial variables. The changes in the seasonal rainfall can be associated to either changes in the rainfall intensity or the rainfall frequency or both.


DJF
MAM
JJA
SON
5.2N
5.0N
4.8N
4.6N
102.6E
103.0E
mm
0 -50
50 - 100
100 - 150
150 - 200
200 - 250
250 - 300
300 - 350
350 - 400
400 - 450
450 - 500
500 - 550
550 - 600

(a)


DJF
MAM
JJA
SON
5.2N
5.0N
4.8N
4.6N
102.6E
103.0E
mm
0 -50
50 - 100
100 - 150
150 - 200
200 - 250
250 - 300
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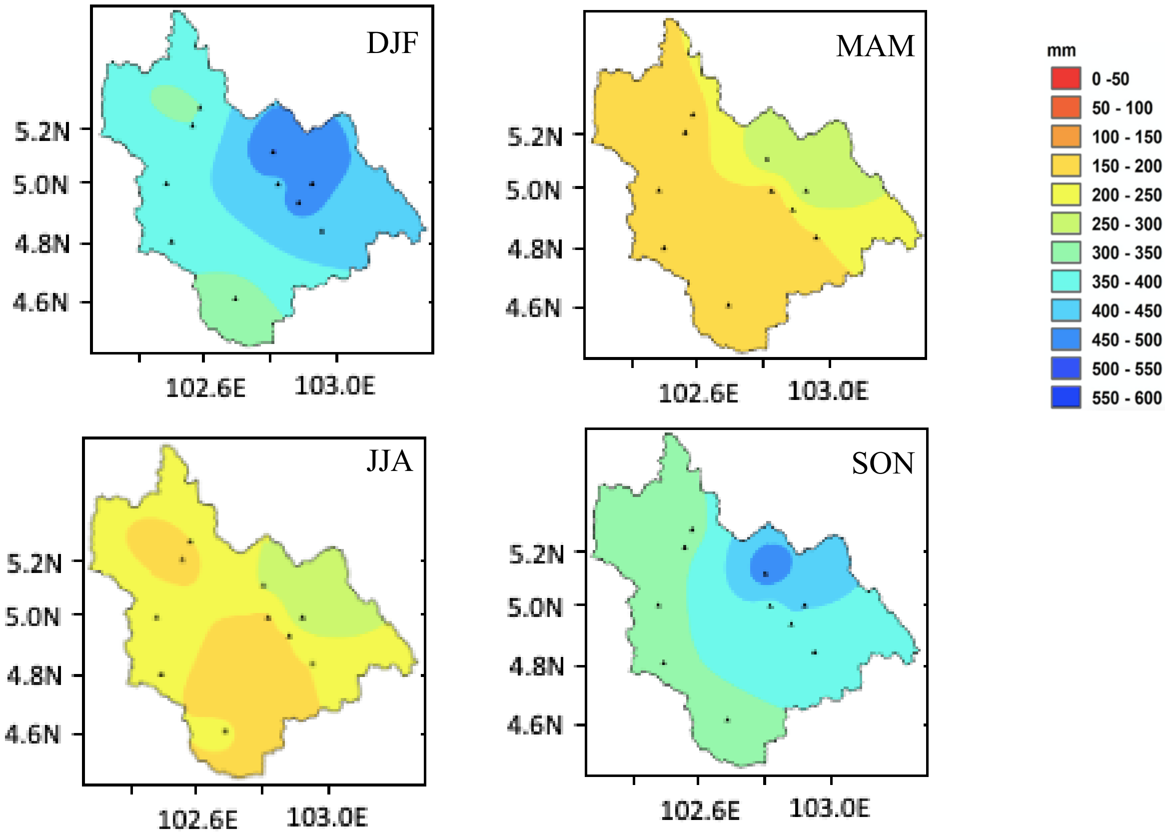
350 - 400
400 - 450
450 - 500
500 - 550
550 - 600

(b)



(c)

Fig. 7 *Projected annual rainfall (ensemble median) by CanesM2 for (a) RCP2.6; (b) RCP4.5; and (c) RCP8.5*

4. Conclusions

The analysis of historical daily rainfall characteristics has suggested remarkable changes in the hydroclimatic regimes over the Kenyir dam catchment. Understanding such changes allows better risk assessment and mitigation planning to ensure water security. Future climate change data, including rainfall for the Kenyir dam catchment were generated from the statistically downscaled CMIP5 GCMs namely the CanESM2, a Canadian Earth System Model. The performance of the CanESM2 was evaluated by comparing the historical rainfall data generated by the CanESM2 with the one from the observations by the ground stations and the three selected GCMs from NAHRIM namely CCSM, ECHM and MRI. Overall, the simulated rainfall patterns closely resemble historical observations. However, the CCSM, ECHM and MRI tend to underestimate monthly rainfall. In contrast, CanESM2 simulations generally produce monthly rainfall that is more consistent with the historical observations for RCP2.6, RCP4.5 and RCP8.5. The projected climate rainfall by the CanESM2 suggests a slight decrease in total rainfall over the Kenyir dam catchment due to global warming.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Siti Nazahiyah, Nurul Nadrah Aqilah;* ***data collection:*** *Muhammad Hanafi;* ***analysis and interpretation of results:*** *Siti Nazahiyah, Nurul Nadrah Aqilah, Hartini;* ***draft manuscript preparation:*** *Siti Nazahiyah. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] Sivakumar, B. (2011) Global Climate Change and Its Impacts on Water Resources Planning and Management: Assessment and Challenges. *Stochastic Environmental Research and Risk Assessment*, *25*, 583-600, https://doi.org/10.1007/s00477-010-0423-y

[2] IPCC (2013) *Climate change 2013: the physical science basis* Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge.

[3] Hamid, H., Rahmat, S. N., Hartini, K. & Tukimat, N. N. (2024) Rainfall projection using CIMP6 models of extreme area in Johor *IOP Conf. Ser.: Earth Environ. Sci.*, *1347*, 012013, https://doi.org./10.1088/1755-1315/1347/1/012013

[4] Azman, H. A., Tukimat, N. N. A., Malek, M. A. (2021) Climate Change Impacts on Hydropower Generation at Kenyir Lake *Journal of Engineering Science and Technology*, *16*(*2*), 1287 – 1298

[5] Tang K. H. D. (2019) Climate change in Malaysia: Trends, contributors, impacts, mitigation and adaptations, *Science of the Total Environment*, *650,* Part 2**,** 1858–1871, https://doi.org/10.1016/j.scitotenv.2018.09.316

[6] Yusof, M. K. T. M., A Rashid, A. S., Mohd Apandi, N., Abduk Khanan M. F., Abd Rahman M. Z., Kalatehjari, R., Ismai, A. & Mohd Salleh, M. R. (2024) Projection of rainfall distribution map under the impact of RCP4.5 and RCP8.5 climate change scenarios: A case study of Penang Island, Malaysia, *Geografia-Malaysian Journal of Society and Space*, *20(2)*, 1 – 22, https://doi.org/10.17576/geo-2024-2002-01

[7] Othman, W. Z. & Tukimat, N. N. A. (2023) Assessment on the Climate Change Impact Using CMIP6, *IOP Conference Series: Earth and Environmental Science*, *1140*, 012005, https://doi.org/10.1088/1755-1315/1140/1/012005

[8] Tang, K. H. D. (2019) Climate change in Malaysia: Trends, contributors, impacts, mitigation and adaptations, *Science of The Total Environment*, 650 (Part 2), 1858-1871, https://doi.org/10.1016/j.scitotenv.2018.09.316

[9] Maturidi, A. M. A. M., Kasim, N., Abu Taib, K., Wan Azahar, W. N. A. & Ahmad Tajuddin, H. (2021) Empirically Based Rainfall Threshold for Landslides Occurrence in Peninsular Malaysia, *KSCE Journal of Civil Engineering*, *25*, 4552-4566, https://doi.org/10.1007/s12205-021-1586-4

[10] Sa'adi, Z., Alias, N. E., Yusop, Z., Hamed, M. M., Shukla, P., Houmsi, M. R., Mohamad, N. A., Shiru, M. S., Sa'adi, N., Muhammad, M. K. I., Iqbal, Z. & Banday, U. J. (2024) Characterization of the future northeast monsoon rainfall based on the clustered climate zone under CMIP6 in Peninsular Malaysia, *Atmospheric Research*, *304*, 107407, https://doi.org/10.1016/j.atmosres.2024.107407

[11] Sa'adi, Z., Alias, N. E., Yusop, Z., Iqbal, Z., Houmsi, M. R., Houmsi, L. N., Ramli, M. W. A., Muhammad, M. K. I. (2024) Application of relative importance metrics for CMIP6 models selection in projecting basin-scale rainfall over Johor River basin, Malaysia, *Science of The Total Environment*, *912*, 169187, https://doi.org/10.1016/j.scitotenv.2023.169187