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Projection of Climate Extreme Indices Based on Representative Concentration Pathways (RCP) in Aceh Province

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ABSTRACT

Representative Concentration Pathways (RCP) scenarios are based on assumptions about the future development of radiative forcing. There are 4 RCP scenarios, but only 2 RCP scenarios are used in this study, RCP 4.5 and RCP 8.5. The aims are to identify characteristics and percentage changes in extreme climate indices in the future. CMIP5 model data such as CCSM4, IPSL-CM5A-LR, IPSL-CM5A-MR, IPSL-CM5B-LR and NorESM1-M were used. The model data was downscaled using a statistical method, and bias correction was based on observational data from five BMKG stations in Aceh Province for the historical period (2001-2005). Subsequently, the observation data and bias-corrected model data for extreme climate events were identified based on the Expert Team on Climate Change Detection and Indices (ETCCDI). The extreme climate indices utilized in this study are consecutive rainy days (CWD), consecutive dry days (CDD), total annual rainfall (Prcptot), monthly maximum temperature (TXx), and monthly minimum temperature (TNn). The results show that the CDD, Prcptot, TXx and TNn climate indices tend to increase in 2021 – 2100 periods. Meanwhile, the CWD decreased. Based on the historical period, all extreme climate indices increased significantly in 2021 - 2100 except TXx, which decreased in 2021 – 2040.

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1. INTRODUCTION

Climate change is a global environmental issue of worldwide concern (Prastiwi et al., 2023). Indications of the phenomenon of climate change can be observed from the increasing or decreasing trend of rainfall and average air temperature in a particular region (Safitri et al., 2023). One of the causes of climate change is the significant increase in air temperature (global warming) on Earth, which began since the Industrial Revolution (Sugiarto, 2019). Climate change has a vast and complex impact on various sectors, such as the agricultural sector (Hidayatullah & Aulia, 2019), the fisheries sector (Maurizka & Adiwibowo, 2021), and the health sector (Amalia et al., 2024). The Intergovernmental Panel on Climate Change (IPCC) made a special report on the impacts that will occur if global warming is 1.5°C. The impacts that will occur if global warming reaches 1.5 °C are increased occurrence of extreme climate events such as extreme temperatures, increased frequency, intensity, and amount of extreme rainfall and drought events (IPCC, 2018).

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Based on the Normal Climate and Climate Change Information Book of Aceh Province in 2022 issued by the Aceh Climatology Station of BMKG, it is stated that there is an increase in air temperature and changes in rainfall patterns in Aceh Province in the period 1982 - 2020 (BMKG, 2022). Therefore, a study of the future climate picture in Aceh Province is very important for adaptation and mitigation efforts of the impacts of climate change. One way to know the picture of extreme climate in the future is with climate projections (Nurlatifah, 2023). The General Circulation Model (GCM) is used to project future climate change scenarios based on Representative Concentration Pathways (RCP) (Majhi et al., 2022). RCPs are scenarios that describe future climate based on the amount of greenhouse gases emitted in future years (Jin Woo et al., 2021; Huang et al., 2020). RCP scenarios define four climate evolution trends, namely RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5 (Bienvenido-Huertas et al., 2022). RCP 4.5 and RCP 8.5 are the most widely used scenarios (Putra et al., 2019) because the RCP 8.5 scenario assumes that there is no policy for handling greenhouse gas emissions (Moussa, 2022) while the RCP 4.5 scenario assumes that all countries in the world take part in mitigation efforts simultaneously and effectively (Thomson et al., in Kusumawati et al., 2020).

Lately, Researchers have carried out some studies about climate projections on regional scales. Putra et al., (2019) found that Indonesia's extreme climate index projections will increase significantly in 2011 - 2100 compared to historical data (1986 - 2005). According to Barung et al., (2019), extreme climate indices have increased in the 2011 - 2100 period against the historical period in Sumatra. In Aceh Province, the projection of extreme rainfall from 2014 - 2050 shows an increase in extreme rainfall trends in Banda Aceh and a decrease in extreme rainfall trends in Meulaboh (Mufti et al., 2017), but the research does not adequately represent Aceh Province because it is only limited to the cities of Banda Aceh and Meulaboh and the parameters used in this study are only rainfall data. Temperature projection in the Aceh Province was done by Ilhamsyah et al., (2023) where the temperature results will increase in the future to reach 5° C, but the research only uses one model and does not consider the estimation of other models. So, further research is needed on the projection of extreme climate indices in Aceh Province.

This research tries to project extreme climate conditions and the percentage of extreme climate change in the future for short-term (2021 - 2040), medium-term (2041 - 2070), and long-term (2071 - 2100) periods in Aceh Province using 5 years of historical data (2001 - 2005). The results of this study are expected to be a reference for stakeholders in Aceh Province who are making policies on adaptation and mitigation of the impacts caused by climate change.

2. METHOD

2.1 Statistical Downscaling

Statistical downscaling is a method that makes use of training data and statistical derivation to determine the relationship between global-scale and local-scale data. The statistical downscaling process uses GCM data and station observation data. In long-term climate studies, GCMs are a spatially and temporally orientated model, a numerical climate prediction tool, and a primary source of information for assessing the effects of climate change (Putra et al., 2019). The resolution of GCMs is very low for predicting local climate influenced by topography and land use, but GCMs may still be used to obtain local-scale information when downscaling techniques are used (Fernandez, 2005). Climate variables such as temperature and precipitation in global models are stored in the form of grid data with a horizontal resolution ranging from 50 - 500 km, then the large grid data is downscaled to get a resolution of 25 km. The statistical downscaling approach consists of several tools, namely correlation, bias correction, and regression.

2.2 Bias Correction

Bias correction is utilized to prepare correction factors for model data before testing the accuracy of the model data. Model data generally still contains systematic bias; therefore, correction is needed so that model data can approach actual conditions (observation data). The GCM model data output in this study is in the form of grids with different spatial resolutions, while the observation data is in the form of points, so it is necessary to calculate the correction factor between the model data and the observation data. Bias correction is conducted by finding the probability distribution function (PDF) and cumulative distribution function (CDF) values from the time series of model data and observation data to get the gamma cumulative distribution transfer function relationship. The equation for obtaining the PDF value can be seen in Equation (1), while the CDF value can be seen in Equation (2) (Putra et al., 2019).

$$pdf(x) = \frac{e^{\left(-\frac{x}{\theta}\right)} x^{(k-1)}}{\Gamma(\mathrm{k})\theta^{k}} \tag{1}$$

$$cdf(x) = \int_0^x \frac{e^{\left(-\frac{x}{\theta}\right)} x^{\Gamma(k-1)}}{\Gamma(\mathrm{k})\theta^{k}} dx' + cdf(0) \tag{2}$$

After calculating the CDF of the modeled and observed data for the historical period (2001 - 2005) based on the Quantile Mapping Equation (Equation (3)), the value of the correction factor can be obtained using Equation (4). Then, the correction factors were used to calculate the model projections until 2100 (Equation (5)).

$$cdf_{observation}\big(f(x)\big) = cdf_{model}(x) \tag{3}$$

$$F_{correction} = \frac{cdf_{observation}}{cdf_{model}} \tag{4}$$

$$cdf_{(corrected\ model)} = F_{correction} \times cdf_{model} \tag{5}$$

2.3 Climate Extreme Indices

The climate extreme indices are one of the parameters used to identify the duration, intensity, and frequency of weather/climate extremes such as drought, flooding, and extreme rain (Ariyani et al., 2022). The climate extreme indices use the ETCCDI (Expert Team for Climate Change Detection and Indices) created by the WMO (World Meteorological Organization), with the focus on detecting and monitoring extreme climate events using daily data series (Zhang et al., 2011). In this study, five extreme climate indices were used such as CDD (Number of consecutive days when rainfall < 1 mm), CWD (Number of consecutive days when rainfall ≥ 1 mm), Prcptot (Total annual rainfall amount on wet days), TXx (Monthly highest temperature value of daily maximum temperature) and TNn (Monthly lowest temperature value of daily minimum temperature). Further explanation of the extreme climate index can be seen in Table 1.

Table 1 Climate Extreme Indices.

Index	Description	Unit
TXx	The highest monthly value of the maximum daily temperature	°C
TNn	The lowest monthly value of the maximum daily temperature	°C
PRCPTOT	The total amount of annual rainfall	mm
CDD	The highest number of consecutive days when rainfall < 1 mm	Days
CWD	The highest number of consecutive days when rainfall ≥ 1 mm	Days

2.4 Percentage change in climate extreme index

The projection results are compared to the historical data to see changes in future climate extreme index patterns. The percentage change value of the climate extreme index between the projected and the historical conditions is calculated using Equation (6):

$$ETCCDI\ Change = \frac{(ETCCDI_{Projection} - ETCCDI_{Historical})}{ETCCDI_{Historical}} x\ 100\ \%. \tag{6}$$

ETCCDI change is the percentage change of the projection period to the historical period, projected ETCCDI is the corrected GCM projection climate extreme index while historical ETCCDI is the bias-corrected GCM historical climate extreme index.

3. RESULTS AND DISCUSSION

Parameters for the projection are rainfall, minimum temperature, and maximum temperature variables using five GCMs such as CCSM4, IPSL-CM5A-LR, IPSL-CM5A-MR, IPSL-CM5B-LR, and NorESM1-M. According to Putra et al. (2019), the five models have the highest correlation to simulate the future climate change projections in Indonesia. This study used those models to determine future climate projections in Aceh Province. The results of the bias correction calculation are applied to each parameter in the projection period and calculated into extreme climate indices. All extreme climate indices are plotted in time series. The multi-model ensemble (MME) is the average of the five GCM models.

3.1 CWD Projection

Figure 1 is the result of the time series plot of five GCMs that had been bias-corrected for the period of 2021 - 2100 for the climate index of the number of consecutive rainy days (CWD). Figure 1a is a projection of the maximum number of consecutive rainy days with the RCP 4.5 scenario, while Figure 1b is a projection of the maximum number of consecutive rainy days with the RCP 8.5 scenario. Both scenarios showed a decreasing trend in the maximum number of consecutive rainy days in the period 2021 - 2100. The downward trend of the RCP 4.5 scenario is greater than the downward trend of the RCP 8.5 scenario with a decrease of 0.0215 days/year, but the maximum number of consecutive rainy days in the RCP 8.5 scenario is higher than in the RCP 4.5 scenario. The maximum number of consecutive rainy days in the RCP 4.5 scenario ranges from 11 - 50 days/year while in the RCP 8.5 scenario ranges from 19 - 50 days/year. The results obtained in the CWD climate index are different compared to those conducted by Putra et al. (2019) and Barung et al. (2019). In Putra et al. (2019), the CWD index experienced an insignificant increase in trend. Whereas Barung et al. (2019) found that the CWD index in the RCP4.5 scenario increased in 2011 - 2040 and then decreased until 2100 while in the RCP8.5 scenario, it decreased until 2100. This is due to the area and history period used in the study, where Putra et al. (2019) conducted research in Indonesia and Barung et al. (2019) conducted research in Sumatra with each using 20 years of historical data (1986 - 2005).

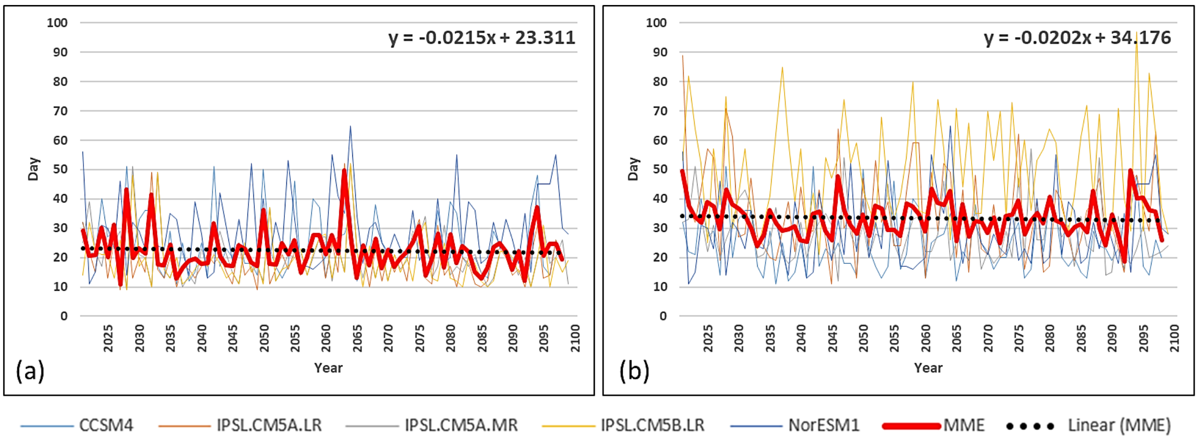

Figure 1 (a) RCP 4.5 CWD Projection and (b) RCP 8.5 CWD Projection.

3.2 CDD Projection

Figure 2 is the result of a time series plot of five GCMs that have been bias-corrected for the period 2021 - 2100 for the climate index of consecutive dry days (CDD). Figure 2a is a projection of the maximum number of consecutive dry days with the RCP 4.5 scenario while Figure 2b is a projection of the maximum number of consecutive dry days with the RCP 8.5 scenario. It can be seen that in both scenarios the maximum number of consecutive dry days experienced an increasing trend in the period 2021 - 2100. The increasing trend in the RCP 8.5 scenario is higher than the increasing trend in the RCP 4.5 scenario with an increase of 0.1599 days/year. The increase in the CDD climate index also occurred in research conducted by Barung et al. (2019) for both scenarios. However, research conducted by Putra et al. (2019) showed a decrease for both scenarios in the future.

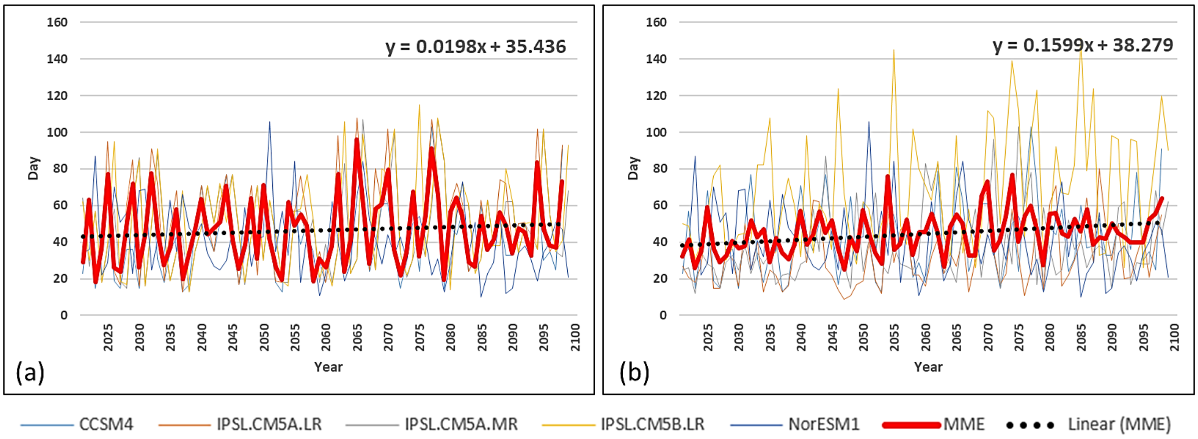

Figure 2 (a) RCP 4.5 CDD Projection and (b) RCP 8.5 CDD Projection.

3.3 Prcptot Projection

Figure 3 is the result of a time series plot of five GCMs that have been bias-corrected for the period 2021 - 2100 for the total annual rainfall climate index (Prcptot). Figure 3a is a projection of total annual rainfall with the RCP 4.5 scenario while Figure 3b is a projection of total annual rainfall with the RCP 8.5 scenario. It can be seen that the projection of total annual rainfall in the RCP 4.5 scenario has a downward trend of 0.8853 mm/year while the RCP 8.5 scenario has an upward trend of 0.7941 mm/year. There is a difference between the results of the Prcptot climate index in the research of Putra et al. (2019) and Barung et al. (2019). In Putra et al. (2019), the Prcptot index increased in both scenarios, while in Barung et al. (2019), the Prcptot index increased in 2011 - 2040, but decreased in 2041 - 2100.

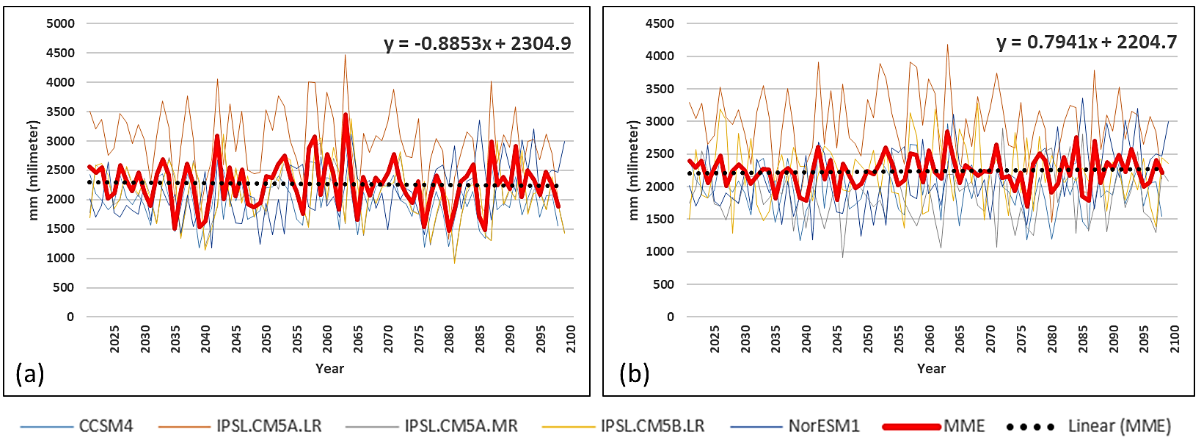

Figure 3 (a) RCP 4.5 Prcptot Projection and (b) RCP 8.5 Prcptot Projection.

3.4 TXx Projection

Figure 4 is the result of a time series plot of five GCMs that have been bias-corrected for the period 2021 - 2100 for the monthly maximum temperature climate index (TXx). Figure 4a is the maximum monthly temperature projection with the RCP 4.5 scenario while Figure 4b is the maximum monthly temperature projection with the RCP 8.5 scenario. It can be seen that the projected monthly maximum temperature for both scenarios have the same pattern, namely experiencing an increasing trend in monthly maximum temperature in the period 2021 - 2100. The increasing trend in the RCP 8.5

scenario is higher than the increasing trend in the RCP 4.5 scenario with an increase of 0.0202 ° C /year. The increase in the TXx climate index in the future also occurred in research conducted by Putra et al. (2019) up to 4 - 6 °C, Barung et al. (2019) up to 4 - 5.5 °C, and Ilhamsyah et al. (2023) up to 5 °C.

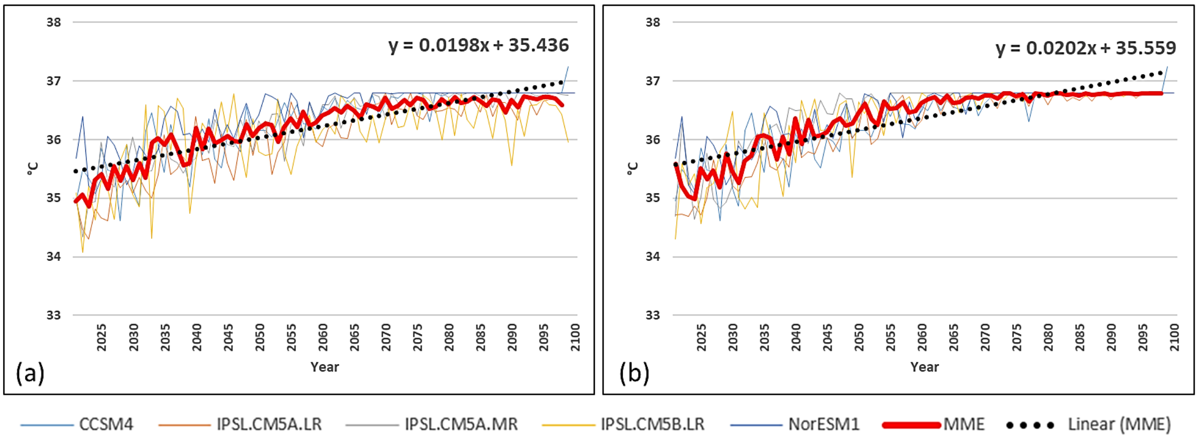

Figure 4 (a) RCP 4.5 TXx Projection and (b) RCP 8.5 TXx Projection

3.5 TNn Projection

Figure 5 is the result of a time series plot of five GCMs that have been bias-corrected for the period 2021 - 2100 for the monthly minimum temperature climate index (TNn). Figure 5a is a projection of the monthly minimum temperature with the RCP 4.5 scenario while Figure 5b is a projection of the monthly minimum temperature with the RCP 8.5 scenario. It can be seen that the projected monthly minimum temperatures for both scenarios have the same pattern, namely experiencing an increasing trend in monthly minimum temperatures in the period 2021 - 2100. The increasing trend in the RCP 8.5 scenario is higher than the increasing trend in the RCP 4.5 scenario with an increase of 0.0534 °C/year. The monthly minimum temperature in the RCP 4.5 scenario ranges from 19 - 23 °C while in the RCP 8.5 scenario, it ranges from 20 - 24 °C. The increase in the TNn climate index in the future also occurred in research conducted by Putra et al. (2019) up to 4 - 6 °C, Barung et al. (2019) up to 4 - 5.5 °C, and Ilhamsyah et al. (2023) up to 5 °C.

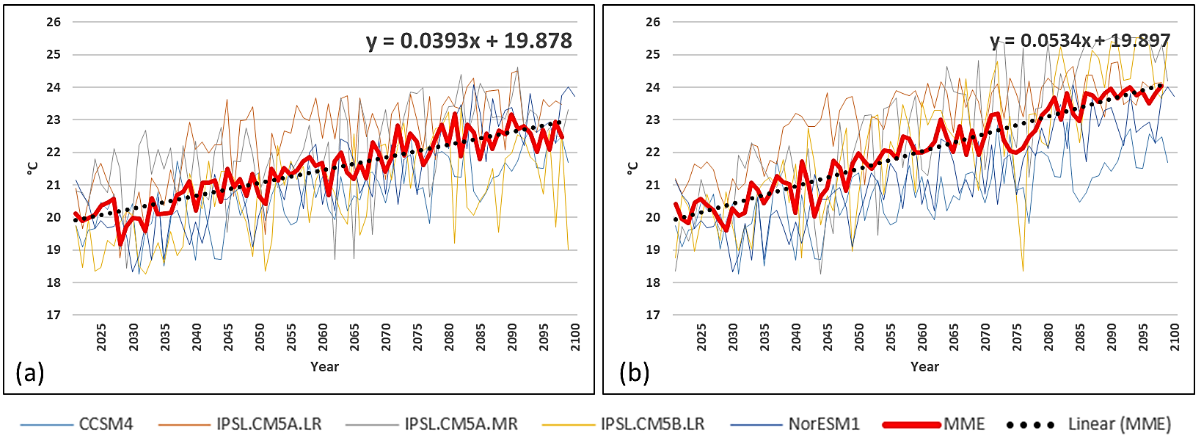

Figure 5 (a) RCP 4.5 TNn Projection and (b) RCP 8.5 TNn Projection.

3.6 Percentage Change in Climate Extreme Index

Based on the results of MME calculations from five GCMs in the projection period, the extreme climate indices CWD, CDD, Prcptot, and TNn show a relative increase compared to the historical period in all time spans. The TXx climate index did not change in the short period under both scenarios but experienced a relative increase in the medium and long periods. The percentage changes in the five extreme climate indices can be seen in Table 2.

Table 2 Percentage changes observed in the five extreme climate indices in Aceh Province.

Climate Extreme Index	RCP 4.5			RCP 8.5		
	Short 2021 - 2040	**Medium 2041 - 2070**	**Long 2071 - 2100**	**Short 2021 - 2040**	**Medium 2041 - 2070**	**Long 2071 - 2100**
CWD	167 % ↑	156 % ↑	144 % ↑	289 % ↑	267 % ↑	267 % ↑
CDD	87 % ↑	104 % ↑	113 % ↑	65 % ↑	96 % ↑	113 % ↑
Prcptot	8 % ↑	12 % ↑	7 % ↑	5 % ↑	9 % ↑	8 % ↑
TXx	0 %	2 % ↑	3 % ↑	0 %	3 % ↑	4 % ↑
TNn	8 % ↑	14 % ↑	20 % ↑	10 % ↑	17 % ↑	25 % ↑

4. CONCLUSION

Based on the characteristics of temporally climate extreme index projections for consecutive dry days climate index, total annual rainfall, monthly maximum temperature, and monthly minimum temperature experienced an increasing trend in all periods, while consecutive rainy days climate index experienced a downward trend. Based on the analysis of the percentage change in climate extreme indices between the projection period and the historical period, all extreme climate indices including consecutive rainy days, consecutive dry days, total annual rainfall, and monthly minimum temperature have increased in all periods, while the climate index for monthly maximum temperature has no change in the short term, but has increased in the medium and long term. It means, in the future the days without rain and the days with rain will increase but will decrease until 2100, the amount of rainfall will increase, and the temperature will get hotter.

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