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Climate Change and Food Security: A Case Study in MUDA Agricultural Development Authority (MADA)

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Climate change has attracted much attention globally due to its influence on weather patterns, leading to extreme events. In Malaysia, rising temperatures and rainfall distribution shifting pattern have led to floods and droughts, particularly affecting agricultural areas including rice fields. Among 13 granary areas in Malaysia, MADA is the largest and has been significantly impacted by the changing climate. It is crucial to identify the changes in rainfall patterns and temperature in MADA, as it directly affects crop yields and contribute to potential food security issues. Six locations within MADA were selected. Historical data from 1991 to 2020 obtained from MetMalaysia and future climate projections from CMIP5 for RCP 4.5 and RCP 8.5 climate scenarios were analyzed using Mann-Kendall (MK) test, precipitation concentration index (PCI), standardized precipitation anomaly (SPA), and temperature anomaly. The evaluation of the future projections included 3 different time periods: the early century (2020 to 2046), the middle century (2047 to 2073), and the late century (2074 to 2099). The MK test detected an escalating trend of RCP 4.5 and RCP 8.5 seasonal rainfall throughout the centuries except during late century of RCP 4.5. The SPA values portray no drought projected while PCI values represents irregular rainfall during main season. Temperature projected to increase up to 2.74 °C for RCP 4.5 and 4.83 °C for RCP 8.5. Yield projections were simulated using DSSAT 4.8 to analyse the impact of future climate on rice yields. Average yield projected for RCP 4.5 could be reduced by 18 % during early century; 21 % during middle century and 24 % during late century compared with 2021 yield data. As for RCP 8.5, average yield projected could be reduced by 19 % during early century; 22 % during middle century and 26 % during late century. This study will provide valuable insights for decision-makers and researchers in formulating effective adaptation and mitigation approaches to safeguard food security and promote sustainable development in the future.

1. Introduction

Rice is a staple food in Malaysia feeding the population of approximately 32.70 M as of 2022. Corresponding to the Department of Statistics Malaysia, the per capita rice consumption in Malaysia was approximately 78 kg in 2019 (DOSM, 2023) with only 71.6 % of the domestic demand met by domestic rice production. The Agriculture and Food Security (MAFS) has set national rice SSL target at 75 % by 2025 and 80 % by 2030, aligned with the National Food Security Policy Action Plan 2021-2025 and National Agro-Food Policy 2021- 2030 (DAN 2.0) due to world food crisis that happened in 2008 besides sustaining food security to feed the growing population. As a result, the national average rice yield should exceed 5 t/ha. Malaysia is currently ranked 41st on the Global Security Food Index (GSFI), indicating some challenges in ensuring food security. Malaysia faces the issue of inadequate food production to meet the needs of the population besides industries, with agricultural production standing at only 45 % of the mean for high-income countries (DOSM, 2023). The worsening impacts of climate change disrupt food systems and lead to higher levels of food spoilage, resulting in a decrease in the overall food supply and intensifying concerns about food security (Benton et al., 2022). Granaries are designated as

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major irrigation scheme areas, covering over 4,000 ha, and have been officially recognized by the Malaysian Government as the primary rice-producing regions in line with the National Agriculture Policy (NAP). In Malaysia, there are 13 granary areas, where MADA (Muda Agricultural Development Authority) is the biggest rice-growing region. High temperatures pose a constraint on rice production, as the ideal temperature range for rice cultivation falls between 24 °C and 34 °C. Variations in rainfall, including droughts and floods, influence yield production as the optimal rainfall requirement is more than 2000 mm yearly (Tan et al., 2021). These adverse weather conditions pose a challenge to Malaysia's goal of maintaining rice self-sufficiency beyond 65 %, the minimum national requirement (Mahmood et al., 2022). This study aims to determine the effects of future climate projection towards rice yield production which will assist researchers and decision makers in creating suitable strategies to adapt and mitigate the effects of climate change to ensure food security and promote sustainability for the time head.

2. Materials and Methods

2.1 Study area and future climate projection

Based on data availability, six locations within MADA were chosen for this study. Historical weather data across 1991 to 2020, obtained from MetMalaysia, were utilized, along with future climate projections based on two different scenarios: RCP 4.5 and RCP 8.5. These projections were generated by a multi-model ensemble of climate models downscaled from CMIP5 (Coupled Model Inter-comparison Project). The future projection data were analyzed for three different time periods: the early century (2020–2046), middle century (2047–2073), and late century (2074–2099).

2.2 Trend analysis

Mann Kendall (MK) analysis is a non-parametric test that accepts independent data, takes outliers into account, and is only applied to trustworthy data (Nyikadzino et al., 2020). The MK test is used globally in meteorological parameters trend analysis (Tabari et al., 2015) as MK test has been effective when the data not normally distributed. The World Metrological Organization (WMO) has been broadly recommended this test for free trend assessment by public besides detecting statistically significant trends of long-term data. Eq(1) is used for MK tests calculation (Komlan et al., 2017).

$$S=\sum_{k=1}^{n-1}\sum_{j=k+1}^{n}\operatorname{sign}(x_j-x_k),\ \operatorname{sign}(x_j-x_k)=\begin{cases}+1;(x_j-x_k)>0\\ 0;(x_j-x_k)=0\\ -1;(x_j-x_k)<0\end{cases} \tag{1}$$

A positive S value signifies an increasing trend, tho a negative value implies the opposite. To calculate the variance of the rainfall, the Z value is obtained. Variance (S) is computed as Eq(2), where g is tied groups quantity in the data set; t_p is p^{th} tied group data quantity and n is time series data quantity.

$$\operatorname{Var}(S)=\frac{\left\{n(n-1\_(2n+5)-\sum_{p=1}^{g}t_p\left(t_p-1\right)\left(2t_p+5\right)\right\}}{18} \tag{2}$$

A positive value of S indicates an increasing trend in the time series while a negative value of S implies the opposite. As for n>10 (observations more than 10), Z (standard normal random variable) can be applied for hypothesis testing based on Eq(3).

$$Z=\frac{S\pm1}{\operatorname{Var}(S)^{\frac{1}{2}}} \tag{3}$$

where, S-1 if S>0, S+1 if S<0, and Z is 0 if S=0. A positive value of Z implies an upward trend in the time series over the time while a negative value for Z indicates the opposite (Saimi et al., 2020).

The Sen’s Slope (SS) estimator test is a non-parametric test technique that was used to demonstrate linear patterns and is more efficient than the method using regression equations. The WMO suggests using this test as a component of hydrometeorological data trend detection. (Aditya et al., 2021). If a time series possesses a linear trend, simple non-parametric method can be used to determine the true slope. In the sample of n pairs of data, SS test being used to calculate the trend slope as in Eq (4).

$$Q=\frac{(x_j-x_k)}{(j-k)}\ \text{for i=1,........N} \tag{4}$$

Slope estimates will be N = n(n-1)/2, if there are n values of x_j in the time series and the value of Q_i is sorted from smallest to largest. A two-tailed test estimated the value of Q_{med} at a confidence interval of 90 % and 95 %, which is calculated as in Eq(5).

$$Q_{med}=\begin{cases} Q_{\left[\frac{N+1}{2}\right]} & \text{, if N is odd} \\ \frac{Q_{\left[\frac{N}{2}\right]}+Q_{\left[\frac{N+2}{2}\right]}}{2} & \text{, if N is even} \end{cases} \tag{5}$$

If the Q_{med} shows a positive value, it signifies that the trend is an upward (increasing) trend, while a negative value shows a downward (decreasing) trend.

2.3 Rainfall variability

Rainfall variability was determined in this study using Standardized Precipitation Anomaly (SPA) and Precipitation Concentration Index (PCI). At different scales, the PCI value is applied to evaluate rainfall (annual or seasonal) heterogeneity (variety). Eq(6) below was used to determine the PCI values, and Table 1 (Asfaw et al., 2018) shows the classification.

$$PCI_{annual}=\frac{\sum_{i=1}^{12} p_i^2}{\sum_i^{12} p_i}\times 100\text{, where pi is the rainfall amount of } p_i^{th} \text{ month} \tag{6}$$

The SPA calculated using Eq(7) to gauge the droughts frequency and severity (Gao et al., 2022), determine the types of rainfall patterns and enables the identification of wet and dry years across the time series (Table 2).

$$Z=\frac{(x_i-\bar{x}_i)}{s} \tag{7}$$

where, Z is standardized precipitation anomaly; x_i is annual rainfall for a certain year; $\bar{x}_i$ is long-term mean annual rainfall throughout the observation period and s is annual rainfall standard deviation over the observation period.

Table 1: Precipitation Concentration Index (PCI) characteristics

PCI values	Description
<10	Low rainfall concentration (uniform distribution of rainfall)
11–15	Moderate rainfall concentration
16–20	High rainfall concentration
>21	Very high rainfall concentration (irregular distribution of rainfall)

Table 2: Drought severity classes

Value of Z	Drought severity classes
<-1.65	Extreme drought
-1.28 to -1.65	Severe drought
-0.84 to -1.28	Moderate drought
>-0.84	No drought

2.4 Temperature anomaly

Temperature anomaly is calculated as the difference between the current period (early century, middle century, and late century) with the reference period (historical period).

2.5 Rice yield projection

The DSSAT 4.8 is a sophisticated rice crop growth simulation model based on physiological principles. It has been extensively utilized to study the intricate interplay between rice and its surrounding environment. The specific model employed in this study is the CERES-Rice model, which focuses exclusively on rice crops. For a comprehensive understanding of the model, a detailed description can be found in the work of Jones et al. (2003). The projection analysis was carried out using local current popular rice variety, MARDI Siraj 297.

3. Results and Discussion

3.1 Future climate projection trends

Figure 1 shows that both climate scenarios, rainfall projected to increase during early, middle and late centuries. The MK test and Sen's Slope portray a positive trend (Figure 2a) although it is not significant. Model projections show a 7 % rainfall increase during early century, 14 % during middle century and 7 % during late century under RCP 4.5 as compared to historical period, while under RCP 8.5, rainfall projected to increase by 5 % rainfall increase during early century, 15 % during middle century and 23 % during late century.

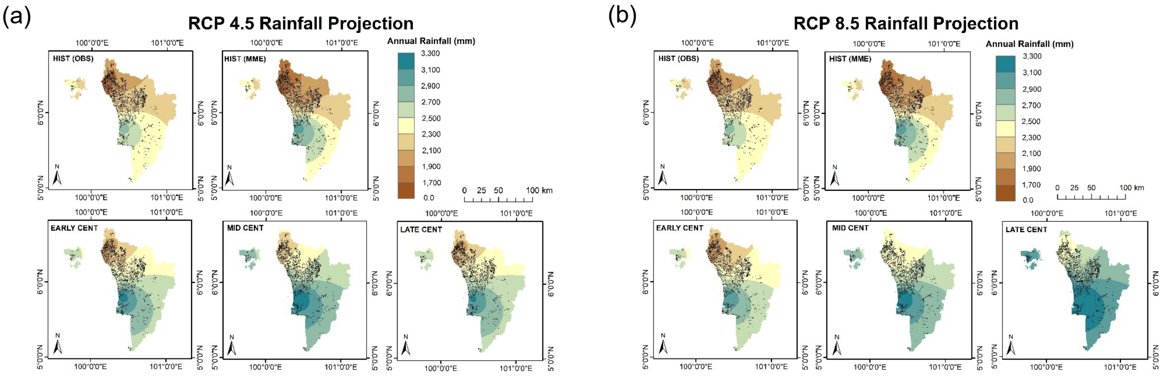
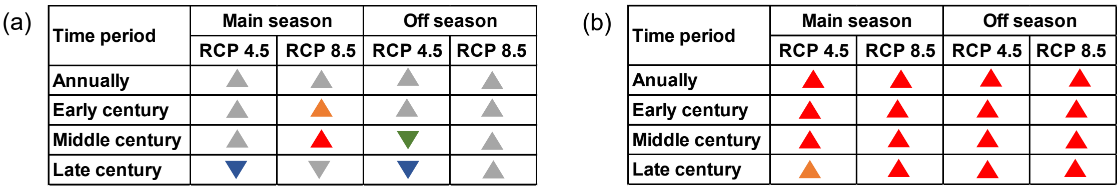


Figure 1: (a) Future rainfall projection under RCP 4.5 climate scenario, and (b) future rainfall projection under RCP 8.5 climate scenario

As for seasonal rainfall, under both climate scenario, MK test and Sen's Slope (Figure 2a) discovered an increasing rainfall trend throughout the centuries except during off season of middle and late century for RCP 4.5 and during main season of late century for RCP 8.5. Based on Table 1 and Table 3, throughout the centuries for both scenarios, mean PCI values varied between 21 to 22 (>21) during main season, representing a very high rainfall concentration (irregular rainfall) whereas annually and during off season, the values varied between 11 to 15, defining a moderate rainfall concentration. Mean SPA values varying between 0.93 to 3.38 (Table 3) implies that no drought projected to occur in the future as Z >-0.84.

Table 3: Mann Kendall's trend analysis of rainfall projection in MADA

	Planting season	Early century		Middle century		Late century	
		RCP4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Mean PCI	Annual	11	13	11	14	11	13
	Main season	21	21	22	21	22	22
	Off season	14	13	14	14	15	13
Mean SPA	Annual	1.76	1.49	2.37	2.60	2.03	3.38
	Main season	0.93	1.08	1.54	1.94	1.24	2.46
	Off season	1.31	0.75	1.55	1.21	1.46	1.63



(a)

Time period	Main season		Off season	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Annually	▲	▲	▲	▲
Early century	▲	▲	▲	▲
Middle century	▲	▲	▼	▲
Late century	▼	▼	▼	▲

(b)

Time period	Main season		Off season	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Anually	▲	▲	▲	▲
Early century	▲	▲	▲	▲
Middle century	▲	▲	▲	▲
Late century	▲	▲	▲	▲

Figure 2: (a) MK test and Sen's Slope for rainfall projection trends. Up (down) grey colour shows a positive (negative) trend. Red (blue) up (down) signifies a positive (negative) trend at 95 % confidence level. Orange (green) indicates a positive (negative) trend at a 90 % confidence level, (b) MK test and Sen's Slope for temperature projection trends. Upward red colour implies a positive trend at 95 % confidence level. Upward orange colour signifies a positive trend at 90 % confidence level.

Farmers are compelled to adapt their cropping systems, adjust planting or sowing times, modify crop varieties, and even switch to different crops in response to rainfall-related hazards and disasters as droughts and floods (Ndamani and Watanabe, 2015). The Precipitation Concentration Index (PCI) serves as an effective tool for quantifying the relative distribution of rainfall patterns (Mondol et al., 2018). By analyzing the PCI and Standardized Precipitation Anomaly (SPA) values, it becomes apparent that floods are projected to occur during the main growing season throughout the centuries for both scenarios. Moreover, the PCI can serve as an indicator of hydrological hazards, including floods and droughts (Gocic et al., 2016). Figure 3 shows that, for both climate scenarios, temperature projected to rise during early, middle and late centuries. The MK test and Sen's Slope portrayed a significant positive trend (Figure 2b). Temperature projected rising up to 2.42 °C by 2099 under RCP 4.5 and up to 4.21 °C under RCP 8.5.

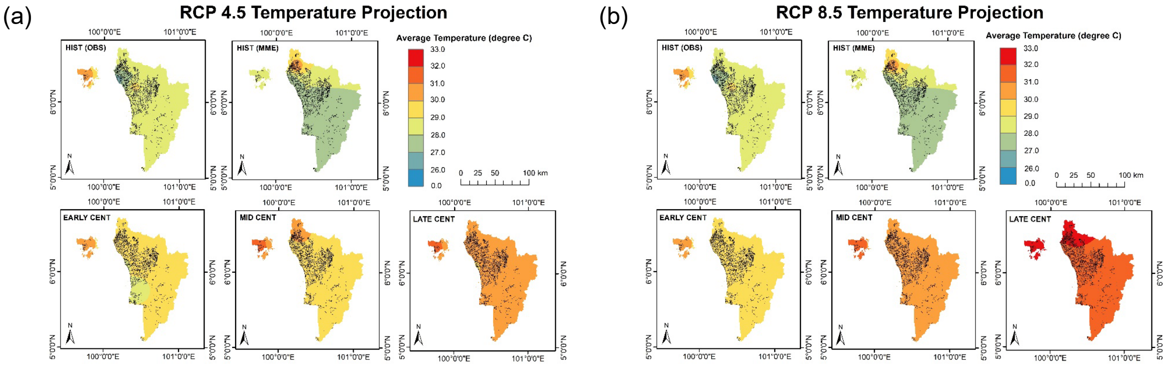


Figure 3: (a) Future average temperature projection under RCP 4.5 climate scenario, and (b) future average temperature projection under RCP 8.5 climate scenario

Table 4: Anomaly of temperature projection in MADA

Planting season	Early century		Middle century		Late century	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Annual	1.22 °C	1.34 °C	1.93 °C	2.70 °C	2.34 °C	4.04 °C
Main season	0.85 °C	1.33 °C	1.93 °C	2.67 °C	2.27 °C	3.94 °C
Off season	1.74 °C	1.37 °C	1.97 °C	2.76 °C	2.42 °C	4.21 °C

3.2 Rice yield projection

Simulation results from DSSAT 4.8 (Figure 4) show that yield will be affected by changing climate trends in the next 80 years. Compared with 2021 yield data (4.19 kg/ha) (MAFI, 2021), annual average yield projected for RCP 4.5 could be reduced by 18 % during early century; 21 % during middle century and 24 % during late century. As for RCP 8.5, annual average yield projected could be reduced by 19 % during early century; 22 % during middle century and 26 % during late century. Increased in temperature potentially influence negative impact on yield production. Correlation studies showed a significant negative correlation between yield and temperature during main season for RCP 4.5 scenario, $r(80)=-0.582$, $p<0.01$ and RCP 8.5 scenario, $r(80)=-0.648$, $p<0.01$. However, during off season, results also showed a negative correlation between yield and temperature although it is not significant, $p>0.01$.

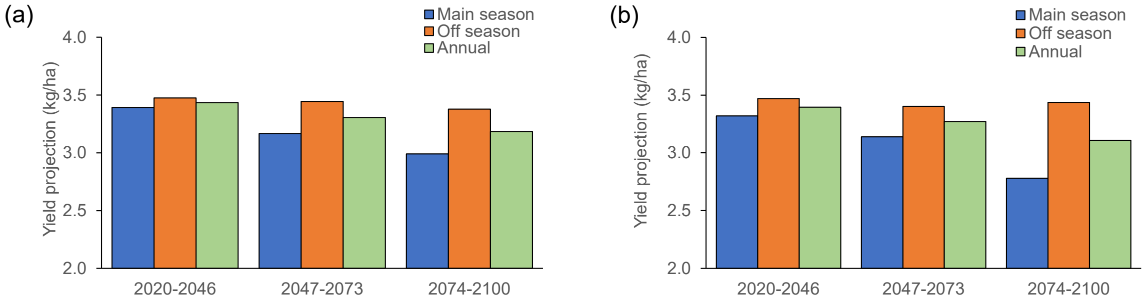


Figure 4: (a) Future yield projection under RCP 4.5 climate scenario, and (b) future yield projection under RCP 8.5 climate scenario

4. Conclusions

The future implications of climate change on rice yield production pose significant concerns for food security. The changing climate, characterized by rising temperatures and altered rainfall patterns, directly impact crop yields. Irregular rainfall patterns are projected to persist throughout the centuries, particularly during the main growing season, which increases the risk of flood events. Temperature projections indicate a potential increase, resulting in reduction of yield production. Malaysia's food systems are highly vulnerable to environmental changes, and the most vulnerable sectors of the population will bear the brunt of future catastrophic events. Urgent evidence-based reforms in the food systems are essential to enable adaptation, mitigation, and recovery from the adverse effects of climate change, ultimately leading to improved population health and a more sustainable planet. Findings from this study can provide valuable data and evidence to support the development of appropriate strategies for adaptation and mitigation by government entities, agencies, and other stakeholders. These strategies aim to enhance adaptive capacity and minimize the impacts of climate change.

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