Adaptation Strategies for Rainfed Rice Production under Climate Change Scenarios in the Songkhram River Basin, Thailand

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***Abstract*— This study investigates the potential impacts and adaptation strategies on rainfed rice production under climate change scenarios in the Songkhram River Basin, Thailand. DSSAT crop simulation model was used to project the future rice production (KDML105 rice variety) based on an ensemble of four Regional Circulation Models (RCMs) for 2020-2044 under RCP4.5 and RCP8.5 scenarios. The projection of future climatic conditions shows an increasing trend in both maximum and minimum temperatures. Maximum and minimum temperatures are expected to rise by 0.9 °C under RCP4.5 scenario, and 1.0 and 1.1 °C under RCP8.5 scenario, respectively. Crop water requirement may be higher by 16 and 17% under RCP4.5 and RCP8.5 scenarios respectively. Temperature rise combined with uncertainties in rainfall may result in water deficits which may increase by 4 and 5% under RCP4.5 and RCP8.5 scenarios, respectively. A pond capacity (600 m^3) is enough to store water for one ha of rice field to meet the potential rice yield during rainfed rice season. The results of this study are helpful to policymakers in understanding the potential impacts of climate change, and the application of adaptation strategies for water and rice sectors in the basin.**

Keywords—Adaptation; Climate change; Rice yield

I. Introduction

Climate change has negative impacts on crop growth and production throughout the world, including many areas in Thailand. Temperature is expected to rise, and rainfall more variable at both global and local scales [6]. Changes in magnitude and patterns of temperature and rainfall could significantly reduce rice production [1][9].

Climate change refers to a change in the weather over a long period of time, including higher surface temperature, floods, droughts, storms, and sea level rise. The global mean surface temperature is expected to rise by 4.8 °C in the twenty-first century [6]. Thailand's temperature is expected to rise by approximately 2–3 ºC during the middle of the century and continue increasing until the end [4]. Climate change affects humanity and the environment, causing higher temperature, changing rainfall patterns, etc. The change in temperature and rainfall affects both the quantity of available water and crops produced. Climate change can be defined as a trend in one or more climatic variables characterized by a fairly smooth continuous increase or decrease of the average value during the long period of record. This trend analysis will aid the assessment of hazard and risk of area and natural disaster by hydro-meteorological extremes such as floods, droughts and cyclones due to the change in climate extremes.

Climate is one of the most important factors in agricultural productivity and could directly influence it since it is linked to physiological processes [5]. This issue could affect global food security, especially in developing countries [1]. Climate change may have both positive and negative impacts on the quantity and quality of agricultural productions, depending on location, climate zone, and crops [5]. Rice is one of the most important agricultural products in the world. Reference [2][3][9] studied the potential climate change impact on rice production in Thailand and concluded that changes in the magnitude and patterns of temperature and rainfall could alter the crop growth period, water availability, photosynthesis process, etc. Temperatures above 35 ºC create high vulnerability of crops and could affect the ripening stage, significantly reducing rice production [10]. Similarly, climate change has influence on rice production and irrigation water requirement in other countries [2].

Uncertainty in future climate projection stem from several sources [5][12][13] and can be minimized by an ensemble of different RCMs [9]. The Decision Support System for Agrotechnology Transfer (DSSAT) model has been used to simulate the impact of CC in many places in Thailand [1][2][3][9] with good model calibration and validation results.

The degree of impact from climate change on rice production depends on the adaptability of each community. Adaptation strategies can greatly reduce the magnitude of impacts on rice production under climate change conditions. Reference [1] suggested that planting dates alteration and proper nutrient management can mitigate the effect of climate change on rice production in northeast Thailand. The changing planting date, reduction in fertility stress and supplementary irrigation were evaluated in the lower Mekong basin [7].

The study aims to investigate the impact of climate change on rice yield, crop water requirement (CWR) and water availability, and evaluate adaptation strategies for farm water management on rice fields for the period 2020-2044 under RCP4.5 and RCP8.5 scenarios in the upper Songkhram river basin of Thailand.

II. STUDY AREA

The Songkhram River Basin is the second largest catchment in Northeast Thailand with an area of approximately 12,700 km^2 (Fig. 1). The Songkhram River which drains the basin is approximately 420 km long and originates at the Phu Phan mountains in the Song Dao District of Sakon Nakhon Province and the Nong Han District in Udon Thani Province. It flows through the Mekong River at Chai Buri Sub-district and Tha Uthen District in Nakhon Phanom.

The basin has a tropical, semi-arid climate with three seasons: summer (March to May), rainy (June to October), and winter (November to February), and receives more annual rainfall than other parts of Thailand [8]. The Thai Meteorological Department (TMD) reported variations in annual rainfall of between 1200 mm and 2000 mm, peaking during the months of July and August. The average mean temperature varies from 21 to 34 ºC. The minimum temperature falls below 10 ºC in the winter season during the months of December and January and rises to over 40 ºC during April in the summer season.

The basin is a floodplain, making it suitable for paddy fields. The Land Development Department (LDD) reported that the majority of land use in the basin is agriculture, covering approximately 68% of the land area. Most of the area consists of paddy fields, Pará rubber, and eucalyptus trees, taking up more than 90% of the agricultural land area in 2010. Household income is mainly reliant on agriculture [8].

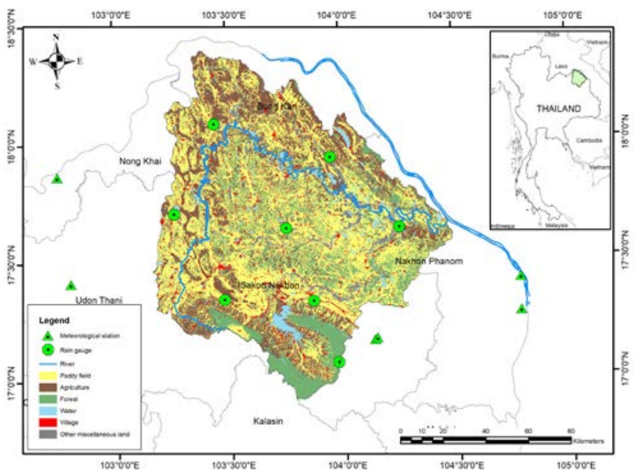


Fig. 1. Location of the meteorological stations, Sakon Nakhon Rice Research Center, and paddy fields in the Songkhram River Basin, Northeast Thailand.

III. METHODOLOGY

The selected Four RCMs (ACCESS1.0-CSIRO-CCAM, CNRM-CM5-CSIRO-CCAM, ICHEC-EC-EARTH-SMHI-RCA4, and MPI-ESM-LR-CSIRO-CCAM) were used to project future climate under RCP4.5 and RCP8.5 scenarios in the basin during the period 2020-2044 based on the observed climate data (1980-2004) from Thai Meteorological Department (TMD). The quantile mapping technique was applied for bias correction (Fig. 2). Missing data can have significant effects on the results, hence the best option is to fill the missing values. In this study, the missing temperature data was estimated using the linear interpolation method and rainfall estimated using APHRODITE's gridded dataset (http://www.chikyu.ac.jp/precip/).

The DSSAT model was used to simulate the future CWR and rice yield (Fig. 2). Rice experiment data from Sakon Nakhon Rice Research Center is used for calibrating and validating the DSSAT model. Calibration was conducted for period 2009-2012, and the period of 2013-2014 was used for validation. The study considered only KDML105 rice variety which is suitable for growth during wet season (June to November). The coefficient of determination (R^2), mean, and standard deviation (SD) were considered for evaluating the model performance. The ensemble of future climate model was used to project the future rice production under climate change scenarios for 2020-2044.

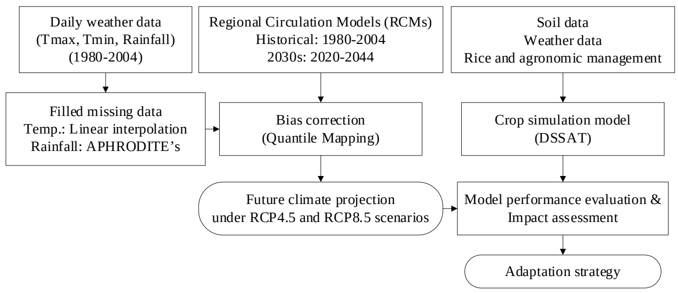


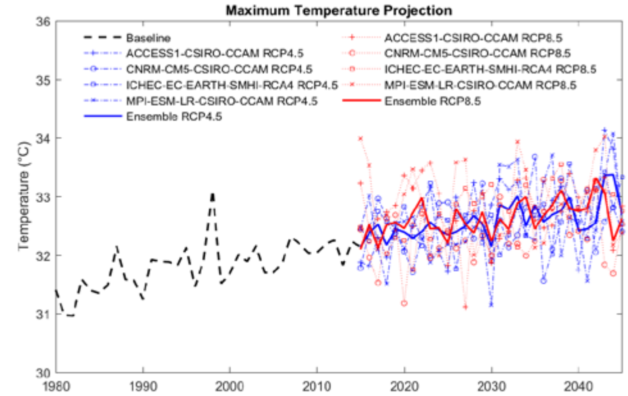
Fig. 2. Methodological framework for assessing the future rice yield and evaluating the adaptation strategy under future climate change scenarios for 2020-2044 in the Songkhram River Basin, Thailand.

IV. RESULTS AND CONCLUSION

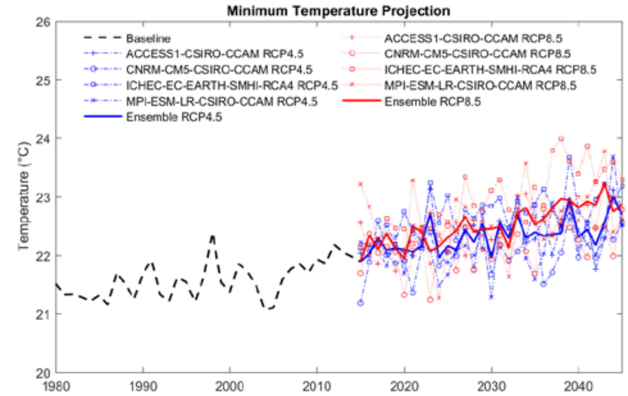
A. Future climate projection

Historical maximum and minimum temperatures show increasing trends. Thai Meteorological Department presented that the maximum and minimum temperatures increased 1.0°C and 0.8°C respectively from 1980 to 2004 in the basin. The average annual maximum temperature is expected to increase by up to 0.9°C and 1.0°C, and minimum temperature expected to increase by up to 0.9°C and 1.1°C for RCP4.5 and RCP8.5 scenarios respectively during 2020-2044, as shown in Fig. 3. Previous studies indicate similar results. The maximum and minimum temperature in Thailand are expected to increase up to 0.95°C and 1.26°C under RCP8.5 scenario for 2016-2043 [9], and 1.47°C and 2.21°C under 437 CO_2 concentration for 2020-2029 [1].

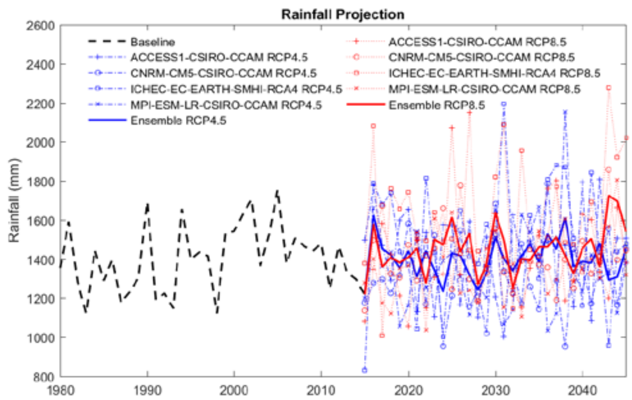
Historical annual rainfall (1980-2004) was varied from 1122 mm to 1705. The peak was in 2002. The average annual rainfall was 1391 mm. The projected rainfall may not much change under climate change scenarios. Future rainfall may increase by 1394 mm and 1458 mm under RCP4.5 and RCP8.5



(a)



(b)



(c)

Fig. 3. Historical and projected (a) maximum temperature, (b) minimum temperature, and (c) rainfall of observation (1980-2004, baseline) and projected (2020-2044) under RCP4.5 and RCP8.5 scenarios.

scenarios respectively. However, the future rainfall will be more variability that can vary from 800 mm to 2300 mm. Past studies have reported that future rainfall may be both increased and decreased in many parts of Thailand. The future rainfall may increase by 19.2% under 437 CO_2 concentration for 2020-2029 in Northeast Thailand [1], may both increase and decrease in the Nam Oon Irrigation Project [9]. This indicates that rainfall varies depending on several variables, including latitude, location, and topography.

B. DSSAT model calibration and validation

The DSSAT v4.6 crop simulation model was used to investigate the effect of climate change on rice yield and evaluate the potential adaptation strategies on rice production in the basin. The rice experiments data from Sakon Nakhon Rice research center of year 2009-2012 were used for model calibration. As farmers did not follow the cropping calendar suggested by the rice department (www.ricethailand.go.th), the 9 July was selected to represent the planting date for KDML105 rice variety in the basin for this study. The errors are acceptable with a coefficient of determination of 0.84. The data for year 2013-2014 was used for model validation. The average observed rice production is 2.08 t/ha, and simulated rice production is 2.07 t/ha. Therefore, the model is suitable for simulating the future rice production under climate change conditions.

Table 3 Performance evaluation of the DSSAT model for the KDML105.

Year	Mean rice yield (t/ha)		RMSE (t/ha)	R^2
	Observation	Simulation		
2009-2012	1.96	1.92	0.009	0.84
2013-2014	2.08	2.07		

C. Climate change impact on rice yield

The crop water requirement (CWR) may increase by 16% and 17% under RCP4.5 and RCP8.5 scenarios, respectively, as shown in Fig. 4. Increased CWR combined with unchanged rainfall may cause future water deficit. Although future rice yield may not change much (2.06 and 1.90 t/ha under RCP4.5 and RCP 8.5 scenarios, respectively) compared with baseline (1.93 t/ha), it is still lower than the potential rice yield of Jasmine rice variety (2.27 t/ha) (www.ricethailand.go.th). Results suggest that supplying water to fulfill CWR can meet the potential rice yield.

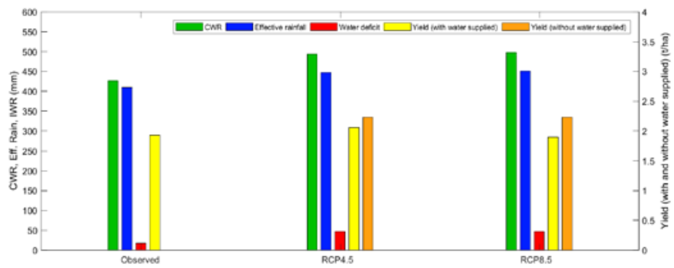


Fig. 4. Impact of climate change on crop water requirement (CWR), effective rainfall, water deficit, rice yield (with and without water supplied).

D. *Adapatation stratigy for rainfed rice production*

This study provides the adaptation option of on farm water management for farmers. The possible option for storing water for paddy fields is pond. Farmers should have their own pond to store the water for one rice season. The assumption is that farmers would have one ha (10,000 m^2) of paddy fields and grow only in the rainfed season. The farmers would have to store about 47 mm/season of extra water plus 20% to allow for losses from evaporation and infiltration. Thus, the pond would be required to store around 564 m^3 of water for one ha of rice field. Therefore, the pond should measure 20 m in width, 15 m in length, and 2 m in depth to store 600 m^3 of water (Fig. 5).

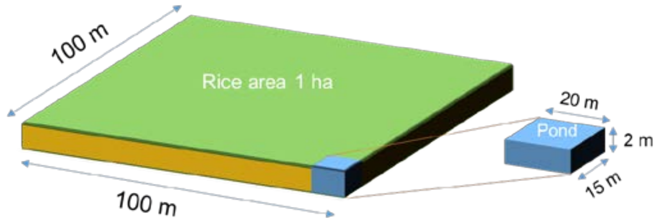


Fig. 5. Adaptation strategy on water management for one ha of rice field.

V. CONCLUSIONS

The future crop water requirement (CWR) and yield were investigated under climate change and a possible measure for on-farm water management in the upper Songkhram river basin was evaluated. Future climate projections during rainfed rice season indicate that maximum and minimum temperatures are expected to rise, while rainfall unchanged under both RCP4.5 and RCP8.5 scenarios for 2020-2044. CWR is expected to increase due to increased temperature and evaporation. Although variations in the future rice yield may not be significant, it is still below potential yield. The future water availability is sufficient to meet the CWR with proper management. It is suggested to have a storage pond (600 m^3) to store water for each ha of rice to overcome water deficit and reach the potential rice yield.

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