Climate Suitability for Paddy in Sukabumi Regency by 2032 Using RCP 4.5 Scenario

W Siska¹,², Widiatmaka³, Y Setiawan⁴⁵ and S H Adi⁶

¹Natural Resources and Environmental Management Study Program, IPB University, Bogor, Indonesia
²Indonesian Agency for Agricultural Research and Development, Bogor, Indonesia
³Department of Soil and Land Resources, IPB University, Bogor, Indonesia
⁴Department of Conservation of Forest and Ecotourism, IPB University, Bogor, Indonesia
⁵Center for Environmental Science, IPB University, Bogor, Indonesia
⁶Indonesian Agroclimate and Hydrology Research Institute, Bogor, Indonesia

Email: widiasiska@apps.ipb.ac.id

Abstract. Climate is the crucial determining component in defining the land suitability class for paddy. The paddy suitability class is expected to decrease as a result of global climate change. This study analyzed land suitability for paddy based on the Representative Concentration Pathways (RCP) 4.5 climate projection scenario of Sukabumi Regency in 2020 and 2032 using the Model for Interdisciplinary Research on Climate (MIROC) 5. The parameters analyzed were precipitation (pr), and near-surface air temperature (tas). The global data was adjusted to local conditions using a bias factor calculated using observed climate data from the Meteorological, Climatological, and Geophysical Agency Station in Bandung. Based on the results of this study, climate (precipitation and temperature) projections for Sukabumi Regency in 2020 and 2032 are classified as highly suitable (S1) for paddy cultivation. The result of this study indicates that there would be no change in the climate suitability class for paddy cultivation in Sukabumi Regency between 2020 to 2032. However, the results of this study also identified a significant numerical decline in precipitation. Therefore, we recommend necessary climate change mitigation and adaptation programs to reduce the future risk of decreasing rice production due to crop failure.

1. Introduction

Sukabumi Regency is one of West Java's rice production centers, contributing to 5% of the province's total rice production [1]. The area of paddy fields in Sukabumi Regency decreased by 8,206 ha, from 63,986 ha in 2014 to 55,780 ha in 2018 [2,3]. The decrease in paddy fields is inversely linked to population growth and food demand. Sukabumi Regency's population increased by 0.19 million from 2.27 million in 2008 to 2.46 million in 2018 [4]. In the future, the gap between the rate of conversion of paddy fields to non-agricultural land uses and population growth in the Sukabumi Regency will increase the risk of food insecurity. On the other hand, climate change poses a threat to the Sukabumi Regency's food sovereignty. Drought affected 7,500 ha of agricultural land in Sukabumi Regency in 2019, with 3,260 hectares of paddy having crop failure [5].
As a result of climate change, increasing rice production to meet the food needs of Indonesian people in the future has become increasingly difficult. Changes in climate variables such as temperature and precipitation impact on rice productivity as caused by climate change [6]. Temperature influences plant evapotranspiration, which determines plant growth period, whereas precipitation determines irrigation water supply [7]. Climatic scenarios are one method of obtaining climate projections to predict future food vulnerability due to climate change. The use of emission scenarios or climate change scenarios is a typical approach to developing climate change projections [8]. Climate change has occurred in Indonesia, according to several studies, with varying effects of change between regions [9]. Quantitative research on the effects of climate change on plant productivity has also advanced quickly. According to Lasco et al. [10] food crop yields in many Asian countries will decline by 2.5 to 10% by 2020 and by 5 to 30% by 2050. In Indonesia, Bappenas [9] projects a decline in crop productivity of 20.3-27.1% for rice, 13.6% for maize, and 12.4% for soybeans, by 2050. Furthermore, Boer et al. [11] stated that the decline in rice production due to the increase in temperature and land-use change in Java in 2025 would reach 6 million tons, and in 2050 it would reach more than 12 million tons with the assumption that the rate of conversion of paddy fields is 0.77% per year.

Changes in emission control parameters, which influence the quantity of Radiative Forcing, are being used to create emission scenarios. An increase in the RF value could result in a warming impact, which increases the world average temperature and causes climate change [8]. The global climate model simulation uses scenario knowledge of changes in RF values as inputs, with the model's output utilized to investigate expected changes in other climate elements. Current climate change scenarios are known as Representative Concentration Pathways (RCP) [12]. The RCP scenario includes a detailed illustration of the future RF path's approximate range. The four scenarios are RCP2.6 (aggressive mitigation strategy, RF increase of 2.6 W m\(^{-2}\)), RCP4.5 (medium–light, RF increase of 4.5 W m\(^{-2}\)), RCP6.0 (medium–high, RF increase of 6.0 W m\(^{-2}\)), and RCP8.5 (business as usual, RF increment of 8.5 W m\(^{-2}\)) [13]. The intensity of the RF value obtained in 2100 is represented by the value in each of these scenarios. The RCP4.5 scenario has the advantage of being in accordance with current efforts to restrict greenhouse gas emissions through the Kyoto Protocol [14], as well as being able to estimate climate change over a shorter time [15]. The RCP 4.5 scenario assumes an RF value of 4.5 W m\(^{-2}\) in 2100, comparable to a CO2 concentration of 650 ppm [16]. The RCP4.5 data shows a stability scenario in which total radiative forcing stabilizes quickly after 2100 without surpassing the long-term target level. In contrast, the RCP8.5 data indicates a scenario in which no stabilization effort is made, and total radiative forcing exceeds 8.5 W/m\(^{3}\) in 2100. This study aims to analyze the suitability of paddy in 2020 and identify the climate of the Sukabumi Regency in 2032 based on RCP4.5 scenarios.

2. Method

This study was carried out in the Sukabumi Regency in West Java, in September-December 2020. Sukabumi Regency is astronomically placed between 6°57′-7°25′ South Latitude and 106°49′-107° East Longitude. This Regency has a total area of 4,145 km\(^{2}\). Sukabumi Regency is bordered on the north by Bogor Regency, on the south by the Indonesian Ocean, on the west by Lebak Regency and the Indonesian Ocean, and on the east by Cianjur Regency.

The materials used in this research are (1) the administrative map of Sukabumi Regency from the Geospatial Information Agency (BIG); (2) precipitation and temperature data from the World Climate Research Program (WCRP); and (3) Sukabumi Regency in Figures. The tool used in this research is a set of computers equipped with ArcGIS 10.5 software and R Studio software.

The first stage of this research was to determine the climatic land suitability of the existing paddy. The second stage was to determine the climate of the Sukabumi Regency in 2032. The parameters analyzed were precipitation and temperature. The output of the Model for Interdisciplinary Research on Climate version 5 (MIROC5) with a climatic scenario of Representative Concentration Pathways 4.5 was used to make the climate predictions. The MIROC5 climate model was developed by the University of Tokyo's Center for Climate System Research (CCSR), the National Institute for Environmental Studies (NIES), and the Japan Agency for Marine-Earth Science and Technology. Climate projection
data can be found at https://esgf-node.llnl.gov/search/cmip5/. A monthly data scale is available from 2006 to 2100, with a 1.5° resolution. Precipitation (pr), near-surface air temperature (tas), and near-surface relative humidity (hurs) are the three climate parameters utilized.

The RCP4.5 is a stability scenario in which total radiative forcing stabilizes quickly after 2100 while being below the optimal long-term value [17]. The ideal scenario is the RCP 2.6 scenario. In this scenario, the mitigation efforts carried out will be able to stabilize the greenhouse gas (GHG) concentration of 450 ppm. However, with the current GHG emission conditions, the target for the RCP 2.6 scenario is challenging to achieve. The scenario that is expected to occur is the RCP 4.5 scenario. RCP4.5 implies that all countries on the globe participate in greenhouse gas mitigation measures concurrently and effectively [18]. The RCP4.5 pathway has attracted much interest.

The precipitation data from the MIROC5 modeling is presented as the monthly mean of the daily precipitation flux in units of kg/m²/s. The unit kg/m²/s is equivalent to mm/s, so for the daily scale, it is necessary to multiply by 24*60*60. To get the monthly precipitation, multiply the monthly mean by the number of days within one month. The monthly mean air temperature value for the near-surface air temperature model MIROC5 is presented in Kelvin units. To convert to Celsius, subtract 273.15. The monthly average relative humidity values, presented in percentage, are included in the data and near-surface relative humidity of the MIROC5 model.

The output of the climate projection of MIROC 5 is climate data resulting from world-scale modeling that requires an adjustment process to local conditions to reflect actual weather data. In this study, the correction of the MIROC5 data was carried out based on the value of the bias factor obtained from the 30-year average value of the model data and observational data [19]. In this study, the data correction is only about 15 years old, adjusting the availability of data on the MIROC5 model (beginning in 2006). Furthermore, the observed data is also limited to February 2021. The calculation of the bias factor uses observed climate data from the nearest station, which is the BMKG station in Bandung. Sukabumi Regency is only covered by two MIROC5 data grids (figure 1), while climate stations in Bandung are on a different grid that is close to the Sukabumi Regency grid. The bias factor value from the Bandung station grid is then applied to the Sukabumi Regency grid.

Figure 1. Pixel coverage of the MIROC5 model climate projection data in Sukabumi Regency. The plus sign indicates the location of the climate station in Bandung.

The Sperna Weiland equation is used to determine MIROC5 data corrections [19]. Equation (1) should be used for precipitation, whereas Equation 2 should be used for air temperature and relative humidity values.

\[
P_{\text{corrected}} = P_{\text{mod}} \times \frac{P_{\text{obs}}}{P_{\text{mod}}} \quad (1)
\]
Explanation:

\[ \bar{P}_{\text{corrected}} = \bar{P}_{\text{mod}} + (\bar{P}_{\text{obs}} - \bar{P}_{\text{mod}}) \]  

(2)

Explanation:

\[ \bar{X}_{\text{corrected}} = \bar{X}_{\text{mod}} \]

\[ \bar{X}_{\text{mod}} \]

\[ \bar{X}_{\text{obs}} \]

\[ \bar{X}_{\text{mod}} \]

According to the Food and Agriculture Organization (FAO), climatic suitability is a classification of a plot of land's suitability for specific plant use. Land suitability is divided into four categories by the FAO, Hardjowigeno, and Widiatmaka: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and unsuitable (N) [20,21]. Physical land suitability evaluates the quality of land by comparing soil unit requirements to plant growth requirements. In this method, the land suitability class is determined by the most severe limiting factor. The criteria for plant growth requirements are based on Hardjowigeno and Widiatmaka’s land suitability criteria, which are presented in Table 1.

Table 1. Criteria for land suitability for paddy.

| Land characteristics                      | Symbol | Land suitability class |
|------------------------------------------|--------|-----------------------|
| Criteria for Permanent Land Characteristics: |        | S1   | S2   | S3   | N1   | N2   |
| Annual Average Temperature (°C)          | (t)    | 24-29 | >29-32 | >32-35 | td   | >35  |
|                                           |        | 22-<24 | 18-<22 |         |      | <18  |
| Water availability                        | (w)    | <3   | 3-<9  | 9-9.5 | td   | >9.5 |
| Dry month (<75mm) precipitation/year     |        | >1500 | 1200-1500 | 800-<1500 | td   | <800 |
| Humidity (%)                             |        | 33-90 | 30-<33 | <30-90 | -    | -    |

Source: Hardjowigeno dan Widiatmaka (2007)

Changes in the climate suitability class of paddy in 2032 were carried out descriptively by comparing the climate suitability data for the existing paddy with the projected suitability.

3. Result and Discussion

3.1 The results of climate projections for Sukabumi Regency in 2020, based on the RCP 4.5 scenario

The analysis of the climate suitability of paddy in the Sukabumi Regency for precipitation parameters was conducted using MIROC5 data. The annual precipitation of Sukabumi Regency is 2,341-2,612 mm/year, with a climate suitability class for paddy classified as highly suitable (S1). The annual air temperature in Sukabumi Regency was also classified as S1, with temperatures between 24.30-24.60°C. Paddy cultivation can be carried out in all regions of the Sukabumi Regency in 2020, based on precipitation and temperature. Table 2 shows the existing climate suitability for paddy, whereas figure 2 shows the temperature and precipitation distribution. Paddy production is possible throughout all regions of the Sukabumi Regency in terms of annual precipitation and temperature.
Table 2. Climate suitability class for paddy based on RCP 4.5 scenario for 2020.

| Climate Parameters | Unit       | Min    | Maks.   | Climate suitability |
|--------------------|------------|--------|---------|---------------------|
| Annual precipitation | mm/year    | 2.341  | 2.612   | S1                  |
| Annual mean temperature | °C        | 24.30  | 24.60   | S1                  |
| Humidity           | %          | 72     | 72.2    | S1                  |
| Dry month          |            | 2      | 2       | S1                  |

Figure 2. Climate projection for paddy suitability in 2020.

3.2 The results of climate projections for Sukabumi Regency in 2032, based on the RCP 4.5 scenario

The results of the climate suitability analysis for paddy based on the RCP 4.5 scenario by 2032 can be seen in table 3 and figure 3. The annual precipitation projection for Sukabumi Regency in 2032 is 1642.40-1843.50 mm/year with a land suitability class classified as S1, with dry months <3 months classified as S2. Humidity is projected in the range of 71.93-72.69%, classified as S1, with an annual average temperature of 24.70-25.00°C, which is classified as S1.

Table 3. Climate suitability class for paddy based on RCP 4.5 scenario for 2032.

| Climate Parameters | Unit       | Min    | Maks.   | Suitability class |
|--------------------|------------|--------|---------|-------------------|
| Annual precipitation | mm/year    | 1642.40| 1843.50 | S1                |
| Humidity           | %          | 71.93  | 72.69   | S1                |
| Annual mean temperature | °C        | 24.70  | 25.00   | S1                |
| Dry month          |            | 3      | 3       | S2                |
The climate suitability class for paddy (precipitation, temperature, and humidity) in 2032 was classified as highly suitable (S1), ensuring that paddy cultivation would not be hampered. Fauziyah et al. in Central Java province claimed that climate characteristics (annual precipitation and annual average temperature) in the years 2031-2040 were highly suitable for paddy cultivation, as were the findings of Barung dan Suwandi in the province of East Java for the years 2021-2030 [14,22].

3.3 Changes in climate suitability of paddy in 2032

For annual precipitation parameters, the climate suitability for paddy in 2032 is still classified as highly suitable (S1), or the land suitability class has not changed from the current year. However, when evaluated in terms of numbers, annual precipitation in 2032 will be significantly lower than 2020. This shows that the risk of drought in paddy cultivation will increase in 2032. As a result, in the Sukabumi Regency, climate change mitigation and adaptation strategies are required to anticipate the impact of climate change and the loss of paddy production. Adjusting a plant schedule, fertilization, and using drought-resistant rice varieties are some of the mitigation and adaptation strategies that can be implemented [23,24].

For annual mean temperature parameters, there was a temperature increase of 0.4°C compared to 2020, even though it was still categorized as S1. High temperatures can be a limiting factor for paddy cultivation. An increase in temperatures can cause paddy pollen sterility [25] and grain calcification [26]. Table 4 demonstrates the development of paddy climatic adaptability throughout time.

Table 4. Changes in paddy climate suitability between 2020 and 2032.

| Climate Parameters      | Unit       | Existing Min | Existing Maks. | Suitability class | 2032 Min  | 2032 Maks.  | Suitability class |
|------------------------|------------|--------------|----------------|-------------------|----------|------------|-------------------|
| Annual precipitation   | mm/year    | 2.341        | 2.612          | S1                | 1.642.40 | 1.843.50   | S1                |
| Annual mean temperature| °C         | 24.30        | 24.60          | S1                | 24.70    | 25.00      | S1                |
Precipitation determines the supply of irrigation water to fulfill plant water needs, although not directly related to plant growth [27]. In line with the findings of this study, Chandradijaya et al. [28] in Sumedang Regency using RCP4.5 reported that precipitation declined by 5.01 percent to 6.21 percent during 2011 and 2040.

4. Conclusion
Based on the results of this study, climate (precipitation and temperature) projections for Sukabumi Regency in 2020 and 2032 are classified as highly suitable (S1) for paddy cultivation. The result of this study indicates that there would be no change in the climate suitability class for paddy cultivation in Sukabumi Regency between 2020 to 2032. However, because there is a significant numerical decline in precipitation, it is necessary to mitigate and adapt to climate change for paddy cultivation to reduce the risk of decreasing rice production due to crop failure. For more detailed information, it is required to employ downscaling techniques on global climate projections data for further research.

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