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The Projection of Rainfall and the Effect on Rice (*Oryza sativa* L.) Productivity until 2045 Based on the *Representative Concentration Pathways* (RCP) Scenario

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***Abstract*— *Rainfall is one of the factors that causes a decrease in rice productivity. The study of rainfall and productivity projections in East Java province is important because it is one of the provinces that contributes the most to rice production in Indonesia. The research aims to study the projection of rainfall and rice productivity until 2045 using the Global Climate Model in the RCP 2.6 and RCP 8.5 scenarios in Malang and Banyuwangi regencies. The study was conducted by examining rainfall variability and its effect on rice productivity in Malang and Banyuwangi regencies in April–May 2024 using BMKG and NASA MERRA-2 rainfall data for 1993–2022, rice productivity for 2003–2022 in Malang and Banyuwangi regencies, and the global climate model until 2045 using the linear scaling method. The results showed that the MOHC-HadGEM2-ES model has a fairly good accuracy in projecting rainfall. Rainfall projections in RCP 2.6 and 8.5 scenarios show changes in rainfall patterns and intensity, with peak rainfall in April-June, where Malang and Banyuwangi regencies have monsoonal rainfall types; in those months the rainy season should have decreased or entered the dry season. The projection of rice productivity until 2045 in the RCP 2.6 scenario shows an increase in productivity in 2045 in Malang and Banyuwangi regencies of 8.02 tons ha^{-1} and 6.87 tons ha^{-1}. The RCP 8.5 scenario shows a decrease in productivity in 2045 in Malang and Banyuwangi regencies of 7.83 tons ha^{-1} and 6.85 tons ha^{-1}.*

Keywords*— *Climate Projection, Rice Productivity, RCP

I. INTRODUCTION

Rice (*Oryza sativa* L.) play an important role in the economy and national food security and as a main commodity for the Indonesian population. Nationally, the need for the provision of rice consumption in Indonesia always increases every year, in line with the increase in population, so it must be balanced with increased production. National rice production in 2003-2010 increased every year but decreased in 2018 and fluctuated until 2022. In 2018, there was a decrease in production of 21.95 million tons or 27.05% compared to 2017 with a production of 81.15 million tons and a productivity of 5.20 tons ha^{-1}. National data on the highest average rice production in 2017-2022 was in East Java province, which was 17.4% (Kementerian Pertanian Republik Indonesia, 2023).

East Java province as one of the highest rice producing centers in Indonesia. Malang and Banyuwangi regencies as the highest rice producing areas. Rice productivity in Malang regency over the past 20 years has fluctuated with the highest productivity in 2013, which was 7.08 tons ha^{-1}, and experienced a decline in productivity until 2022 to 5.92 tons ha^{-1}. Rice productivity in Banyuwangi regency over the past 20 years showed the highest productivity in 2016, which was 6.61 tons ha^{-1}, and experienced a decline until 2022 to 6.02 tons ha^{-1}. Increasing rice production is a major challenge to meet the consumption needs of the Indonesian population which is increasing every year in the future will be even more difficult due to the phenomenon of climate change (Suryana et al., 2022).

Climate change has an impact on the decline in rice production and productivity due to shifts in climate variables, one of which is rainfall. Rainfall is one of the important factors in determining the high and low rice production. Excessive rainfall levels can reduce rice production due to the plants being easily attacked by pests and diseases, thus reducing the quantity of production (Mardawilis and Ritonga, 2016). However, low rainfall can also disrupt rice productivity because it causes drought on the land so that the rice plants dry out, wilt and cause crop failure (Medika et al., 2016). Annual rainfall in 2022 in Malang regency is 3,098 mm (Central Statistics Agency of Malang Regency, 2023) and Banyuwangi regency has an annual rainfall of 1,841.3 mm (Central Statistics Agency of Banyuwangi Regency, 2023). The difference in the amount of rainfall in the two regencies was taken into consideration in selecting the study area where rainfall affected rice productivity, although it had a low level of relationship of 4.43% and the remaining 95.57% was influenced by other factors (Nafisha and Suwarsito, 2018).

The year 2045 is Indonesia's golden year, where Indonesia will be 100 years old. The Ministry of Agriculture is determined to increase food security by realizing food independence and becoming the world food storage. To achieve food security, it is necessary to conduct climate projections until 2045 using a global climate model or Global Climate Model (GCM). The resolution of the GCM is relatively coarse or still on a global scale, so it is necessary to provide more regional or local information in climate change scenarios using RCM and conducting statistical downscaling modeling (Farhan et al., 2022). Statistical downscaling is a statistical model that connects global climate data variables such as GCMs with local-scale climate variables (Fernandez, 2005 *in* Sahriman *et al*., 2019)

The use of climate projections can be applied in various fields, one of which is agriculture. The application of climate change projections in the future can use the Representative Concentration Pathways (RCP) scenario which has four scenarios, namely RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5. Based on the problems that have been described, climate projections were carried out, one of which was on the rainfall variable and its effect on rice productivity until 2045 in the rice centers of East Java province, namely in Malang and Banyuwangi regencies using RCP scenarios on different scales, namely RCP 2.6 and RCP 8.5. The purpose of the study was to study the projection of rainfall and rice productivity until 2045 based on the RCP 2.6 and RCP 8.5 scenarios in Malang and Banyuwangi regencies so that it can predict the realization of Indonesia as the World Food Storage and food independence in 2045.

II. MATERIALS AND METHODS

The research examined rainfall variability and the effect on rice productivity in Malang and Banyuwangi regencies in April–May 2024. Malang regency is located between 112º17'10.90" to 112º57'00" E; between 7º44'55.11'' to 8º26'35.45" S and Banyuwangi regency is located at coordinates 7º45'15" to 8º43'2" S and 113º38'10" E.

The tools used were Microsoft Excel, Statistical Package for the Social Sciences (SPSS) v23, ArcMAP 10.6, Coordinated Regional Climate Downscaling Experiment (CORDEX) and NASA Prediction of Worldwide Energy Resources (NASA POWER). Materials used : BMKG and MERRA-2 NASA rainfall data for 1993–2022, rice productivity for 2003–2022 in Malang and Banyuwangi regencies, and global climate models until 2045. Data analysis was conducted by analyzing changed in monthly rainfall in historical data before and after correction; global climate model validation test; monthly rainfall projection analysis for the periods 2021–2025, 2026–2030, 2031–2035, 2036–2040 and 2041–2045; and simple linear regression analysis to project rice productivity.

Research data

1. Meteorology, Climatology, and Geophysics Agency (BMKG) Rainfall Data

Daily rainfall data for 1993–2022 from the WEB Data Online of the Meteorology, Climatology, and Geophysics Agency (BMKG) Database Center accessed via the page https://dataonline.bmkg.go.id. The station points used are presented in Table 1.

Table 1. BMKG Station Points in Malang and Banyuwangi Regencies

No	Station Name	Longitude	Latitude	Elevate (masl)
1	Climatology Clas II East Java Station	112.59	-7.90	590
2	Meteorology Banyuwangi Station	114.35	-8.21	52

2. Reanalisis MERRA-2 NASA

The Modern-Era Retrospective Analysis for Research and Applications Version 2 (MERRA-2) from The

National Aeronautics and Space Administration (NASA) data can complement the unrecorded BMKG observation rainfall data. NASA's MERRA-2 for 1993–2022 obtained from the NASA POWER WEB is accessed via the page https://power.larc.nasa.gov.

3. Global Climate Model

Global climate model comes from WEB Coordinated Regional Climate Downscaling Experiment (CORDEX) 1993–2045, accessed through the page https://esgf-data.dkrz.de. The period 1992–2005 is used as historical data, 2006–2022 is used as a baseline, and 2022–2045 as a projection model. GCM used is MOHC-HadGEM2, MPI-M-MPI-ESM-MR, and NCC-NorESM1-M. The GCM model is in net CDF (.nc) format, so it is necessary to extract it using ArcMap 10.6 by entering the coordinates of the study area (Table 1).

4. Rice Productivity

Rice productivity data for Malang and Banyuwangi regencies for 2003–2022 was obtained from the East Java Central Statistics Agency.

Data Analysis

1. Bias Correction

Bias correction is used to correct NASA's MERRA-2 data and global climate models because the data has a fairly wide coverage so that it has a fairly high bias value, therefore bias correction needs to be carried out so that it is accurate or can represent the research area to be able to complete observation data or BMKG data (Krismianto, 2015). The method used is Linear Scaling (LS). Linear scaling (LS) is the simplest bias correction method, which only corrects the average model rainfall against the average observed rainfall (Kurnia et al., 2020).

$$P_{cor,m} = P_{raw,m} x \frac{\mu(P_{obs,m})}{\mu(P_{raw,m})}$$

Information:

Pcor, m = Corrected rainfall in month m

Praw, m = Model rainfall in month m

μ(Pobs, m) = Average rainfall observed in month m

μ(Praw, m) = Model average rainfall in month m

2. Validation Test

The validation test uses Root Mean Square Error (RMSE) to determine the magnitude of the error in the Global Climate Model against BMKG observation data. The data used for the validation test is BMKG historical data with model data for 1993–2022 in the RCP 2.6 and 8.5 scenarios. The best model is the model with a smaller RMSE value or closer to 0, meaning it has more accurate prediction results or has a model value that is close to the BMKG data value (Wang and Lu, 2018).

$$\text{RMSE} = \sqrt{\frac{\sum_{i=1}^{i=n}(Yi - Y')^2}{n}}$$

Information:

Yi = Observation rainfall

Y' = Model rainfall

n = Number of data

3. Grouping of Projected Rainfall Changes

Monthly rainfall projections are grouped into 5 periods, namely 2021–2025, 2026–2030, 2031–2035, 2036–2040, and 2041–2045. In these five periods, an analysis of changes in annual rainfall patterns and intensity will be carried out each month in Malang and Banyuwangi Regencies.

4. Projection of Rice Productivity until 2045

The projection of rice productivity until 2045 was carried out using historical observation data from BMKG by analyzing simple linear regression with the dependent variable, namely rice productivity in 2003–2022 and the independent variable, namely observation rainfall data in 2003–2022 in Malang and Banyuwangi regencies using SPSS v23 software.

$$Y = a + bX$$

Keterangan:

Y = Rice plant productivity

a = Constant value

b = Simple linear regression coefficient

x = Rainfall

(Ghozali, 2016).

III. RESULT AND DISCUSION

Completion of Empty Historical Rainfall Observation Data

Bias correction was performed to complement BMKG historical rainfall data using NASA MERRA-2 reanalysis data from 1993–2022. In Malang Regency, the highest average was in February, which was 342.32 mm month^{-1} with a difference of 12.03 mm month^{-1}, while the lowest rainfall was in August, which was 21.15 mm month^{-1} with a difference of 0.87 mm month^{-1}. The wet months were in October–April or a total of 7 wet months, while the dry months were in May–September or a total of 5 dry months (Figure 1). Meanwhile, the average monthly rainfall in Banyuwangi regency with the highest average was in January, which was 270.60 mm month^{-1} with a difference of 38.26 mm month^{-1}, while the lowest rainfall was in September, which was 41.87 mm month^{-1} with a difference of 7.45 mm month^{-1}. The wet months are November–April with 6 wet months, while the dry months are May–October with 6 dry months (Figure 2). Based on rainfall in the two study areas, Malang regency has a higher rainfall compared to Banyuwangi regency (Figures 1 and 2). This is because Malang regency has a topography surrounded by several mountains. The statement by Lesik et al. (2020) that topography and altitude are one of the factors that control the climate in tropical areas, where the higher a place is above sea level, the higher the rainfall level. In mountainous or hilly areas, winds carry water vapor vertically, causing air pressure to decrease, condensation to occur, clouds to form, and rain to fall. In addition to altitude and topography, geographical location is also a factor in rainfall levels. Geographical location is also a factor that influences rainfall patterns in Indonesia because it is close to the equator so that each region does not have the same rainfall (Oktavianingsih et al., 2018). In addition, it is influenced by Sea Surface Temperature (SST), such as the phenomenon that occurs in the Indian Ocean called the Indian Ocean Dipole (IOD), which has an impact on decreasing rainfall in the western part of Indonesia and the El Nino Southern Oscillation (ENSO) in the Pacific Ocean which consists of El Nino and La Nina. El Nino and La Nina have various impacts in Indonesia, especially the impact on monthly and seasonal rainfall. El Nino causes a decrease in rainfall in most parts of Indonesia, especially in June–August and However, several regions in Indonesia September–November by more than 40%.

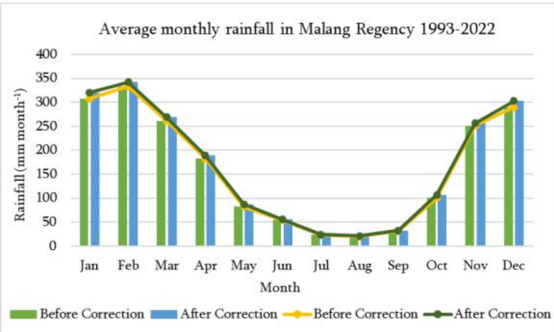

Fig.1. Average Monthly Rainfall in Malang Regency 1993–2022 Before and After Correction

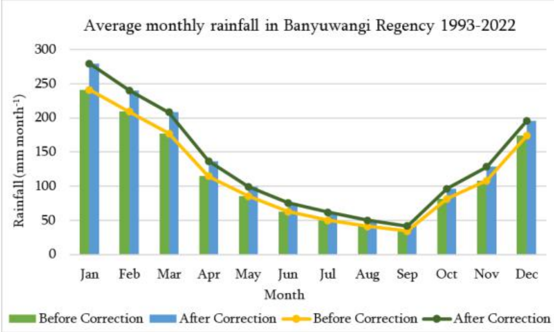

Fig.2. Average Monthly Rainfall in Banyuwangi Regency 1993–2022 Before and After Correction.

experienced increased rainfall in the December–February and March–May periods even though it was El Nino. Meanwhile, La Nina causes increased rainfall in most parts of Indonesia in June–August. The increase in rainfall during La Nina is generally around 20–40% higher compared to neutral rainfall. However, there are several areas that experienced an increase in rainfall of more than 40% (Kedeputian Bidang Klimatologi BMKG, 2020).

Climate Model Validation Test

The results of the RMSE test on the three models in the two study areas obtained the smallest RMSE values in Malang and Banyuwangi regencies in both scenarios, namely RCP 2.6 and RCP 8.5 in the Global Climate Model MOHC-HadGEM2 with values in Malang regency of 13.97 and 13.87; in Banyuwangi regency of 11.80 and 11,57 (Table 2). The MOHC-HadGEM2 model has the lowest prediction error when compared to the MPI-M-MPI-ESM-MR and NCC-NorESM1-M models. So it can be concluded that the MOHC-HadGEM2 global climate model has a prediction with a fairly good level of accuracy in projecting rainfall or has a value close to the BMKG rainfall data so that the MOHC-HadGEM2 model becomes the model that will be used in climate projections and rice productivity until 2045.

Rainfall Projection Until 2045

Rainfall projection using the Global Climate Model in 2 different scenarios, namely RCP 2.6 and RCP 8.5. Based on the results of the validation test between BMKG observation data and global climate model data, it was found that among the three climate models used, the HadGEM2-ES model is the best model when compared to other models (Table 3). The RCP 2.6 scenario is a scenario that makes very strict efforts to reduce the impact of climate change. Meanwhile, the RCP 8.5 scenario is a scenario that assumes a high increase in greenhouse gas emissions, resulting in more extreme climate change. The RCP scenarios are distinguished by differences in radiative forcing (Wm^{-2}) which is a change in the amount of energy entering and leaving the atmosphere due to climate change, such as changes in solar radiation so that this has an impact on the high and low rainfall projections (Agard et al., 2014). The change in radiative forcing in the RCP 2.6 scenario peaks in 2050 at 3 W m^{-2} and decreases to 2.6 W m^{-2} in 2100, while in the RCP 8.5 scenario the radiative forcing continues to increase until 2100, reaching a value of 8.5 W m-^{2}. This causes the rainfall projection to show an increase in rainfall intensity in line with the increase in radiative forcing (van Vuuren et al., 2011).

Rainfall projections in Malang and Banyuwangi regencies in both scenarios show fluctuating rainfall and differences in monthly rainfall distribution during 2021–2045 (Figures 3-8)

Table 2. RMSE Test Results for Projections

GCM	Study Areas	Scenario	*RMSE
MOHC-HadGEM2	Malang Regency	RCP 2.6	13.97
		RCP 8.5	13.87
	Banyuwangi Regency	RCP 2.6	11.80
		RCP 8.5	11.57
MPI-M-MPI-ESM-MR	Malang Regency	RCP 2.6	15.26
		RCP 8.5	14.94
	Banyuwangi Regency	RCP 2.6	13.32
		RCP 8.5	13.15
NCC-NorESM1-M	Malang Regency	RCP 2.6	16.38
		RCP 8.5	15.70
	Banyuwangi Regency	RCP 2.6	12.07
		RCP 8.5	12.21

*Root Mean Square Error

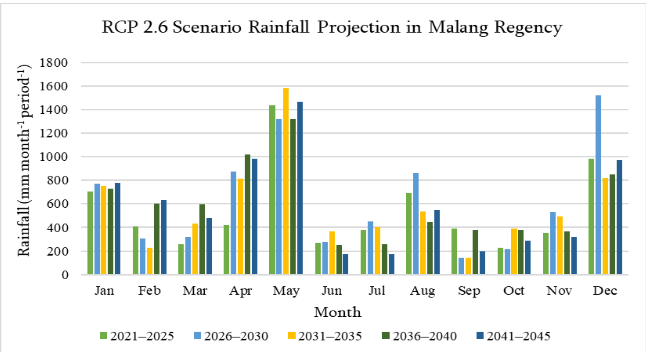

Fig.3. Monthly Rainfall Projection in Malang Regency in RCP 2.6 Scenario

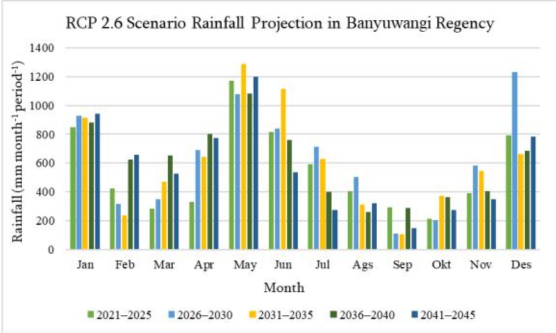

Fig.4. Monthly Rainfall Projection in Banyuwangi Regency in RCP 2.6 Scenario

The projected rainfall has the highest average in May 2031–2035, which is 1,578.42 mm $month^{-1}$. The lowest rainfall is in September 2031–2035, which is 142.84 mm $month^{-1}$ (Figure 3). The rainfall pattern with peak rainfall occurs in April–May and a decrease in rainfall in the dry season occurs in June–July. The projected rainfall has the highest average for each period in May 2031–2035, which is 1,289.12 mm $month^{-1}$ and the lowest rainfall is in September 2031–2035, which is 107.94 mm $month^{-1}$ (Figure 4). The rainfall pattern with peak rainfall occurs in May–June and decreased rainfall in the dry season occurs in August–October.

In RCP 2.6 scenario, the rainfall projection in Malang regency shows peak rainfall in April–May and decreased rainfall in June–July. Meanwhile, in Banyuwangi regency, the peak rainfall occurs in May–June and decreased rainfall occurs in August–October. This shows that despite the increase in rainfall in some months, the RCP 2.6 projection maintains a relatively stable rainfall pattern and intensity, with peak rainfall in the early months of the rainy season and decreased rainfall during the dry season. The RCP 2.6 scenario predicts that it is likely to maintain global temperature increases of less than 2 °C by 2100 and will maintain that there is no drastic climate change. Compared to 1850–1900, global surface temperature changes by the end of the 21st century or by 2081–2100 are projected to be unlikely to exceed 2 °C or by 0.3 °C to 1.7 °C in the RCP 2.6 scenario (IPCC, 2014). The projected rainfall has the highest average for each period in May 2041–2045, which is 1,716.55 mm $month^{-1}$. The lowest rainfall is in June 2041–2045, which is 165.19 mm $month^{-1}$ (Figure 5). The rainfall pattern with peak rainfall occurs in April–May and a decrease in rainfall in the dry season occurs in June–July. The projected rainfall has the highest average for each period in May 2041–2045, which is 1,500.57 mm $month^{-1}$. The lowest rainfall is in September 2031–2035, which is 154.16 mm $month^{-1}$ (Figure 6). The rainfall pattern with peak rainfall occurs in

May–June and a decrease in rainfall in the dry season occurs in August–October.

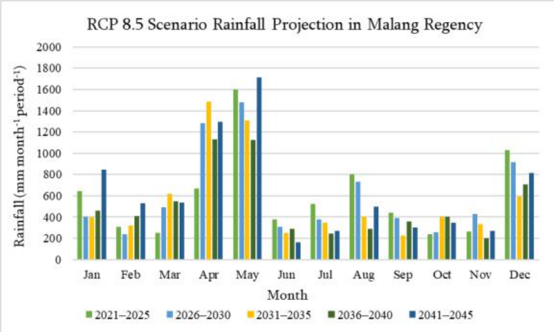

Fig.5. Monthly Rainfall Projection in Malang Regency in RCP 8.5 Scenario

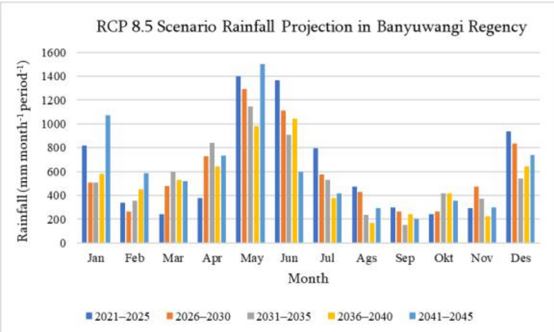

Fig.6. Monthly Rainfall Projection in Banyuwangi Regency in RCP 8.5 Scenario

Meeting the water needs of aquatic plants is very important for the growth and development of rice plants because rice plants are highly dependent on water availability, especially during their growth phase, where the more water is available during the growth phase, the better the growth and production of rice (Rusmawan et al., 2018). The water requirement of rice plants during planting requires water of around 60-70 mm of *dasarian*$^{-1}$ or at least 4 wet months with rainfall above 200 mm month^{-1} consecutively or as much as 1,500-2,000 mm year^{-1}. The water requirement is quite large when the rice plants are in the vegetative phase until the rice grain filling phase and 15-20 days before harvest the rice plants no longer need water (Indratmoko et al., 2017). Rice plants will have a higher productivity value if rainfall in the vegetative phase is higher than in the generative phase because it is to meet the water requirement of rice plants in the vegetative phase of 200-372 mm month^{-1} (Mardawilis and Ritonga, 2016).

Projection of Rice Productivity until 2045

The projection of rice productivity until 2045 was carried out by analyzing simple linear regression to obtain a regression equation, knowing the effect of historical data from BMKG in 2003–2022 as an independent variable on rice productivity data in 2003–2022 as a dependent variable in Malang and Banyuwangi regencies, the equation obtained was Y = 5.558 + 0.000279x in Malang regency and Y = 5.817 + 0.000126x in Banyuwangi regency. The results of the equation obtained were used for the projection of rice productivity until 2045 in Malang and Banyuwangi regencies (Figures 7-8). The results of the projections that have been carried out in both regions, in the RCP 2.6 scenario projected an increase in productivity of 18.58% or rice productivity of 8.02 tons ha^{-1} and the RCP 8.5 scenario projected a decrease in rice plant productivity of 3.75% productivity of 7.83 tons ha^{-1} in Malang regency (Figure 7). In Banyuwangi regency, the RCP 2.6 scenario projected an increase in productivity of 8.67% or productivity of 6.87 tons ha^{-1} and the RCP 8.5 scenario projected a decrease in rice productivity of 0.80% or productivity of 6.85 tons ha^{-1} in Banyuwangi regency in 2045 (Figure 8). The results of the projection of rice productivity until 2045 in Malang and Banyuwangi regencies were only based on 1 aspect, namely rainfall. Rainfall can affect rice productivity even though it has a low relationship level of 4.43% and the remaining 95.57% is influenced by other factors (Nafisha and Suwarsito, 2018).

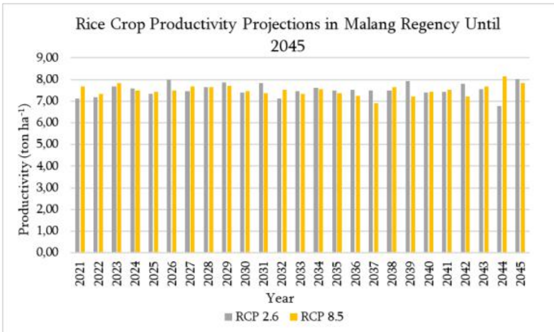

Fig.7. Projection of Rice Productivity in Malang Regency until 2045

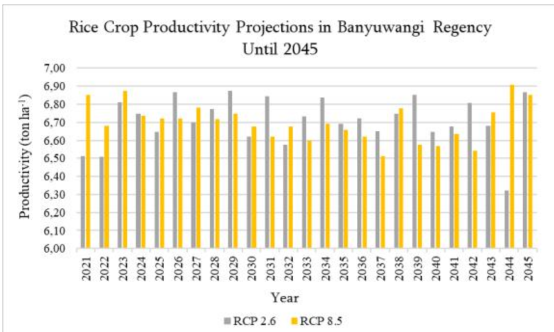

Fig.8. Projection of Rice Productivity in Banyuwangi Regency until 2045

Based on the projections that have been made, it indicates that there is an opportunity for rice productivity in Malang and Banyuwangi regencies in 2045 to exceed the target estimated by the government of the Republic of Indonesia, President Joko Widodo has set a target to make Indonesia the "World Food Storage" in 2045. For this reason, the Minister of Agriculture Dr. Andi Amran Sulaiman has set a self-sufficiency target for several commodities, including rice plants. Towards Indonesia as the World Food Storage, rice production in 2045 is targeted at 100.03 million tons or equivalent to 61.06 million tons of rice with a planting area of 17.83 million ha and a productivity of 5.90 tons ha^{-1}. The achievement of the production target is expected to make Indonesia control 20% of the world's rice market share by 2045 (Sulaiman et al., 2018).

The impact of global climate change in Indonesia, especially on rice production, has been felt and has become a reality. The phenomenon of climate change has triggered an increase in the intensity of extreme events, such as floods and droughts, which cause crop failure and even puso, resulting in a decrease in crop production and productivity, which has the potential to threaten food security (Keputusan Menteri Pertanian Republik Indonesia, 2021). Climate change causes changes in the natural hydrological cycle, which results in natural disasters such as La Nina or an increase in the intensity of rainfall and flooding, and El Nino which can trigger prolonged droughts, causing drought. In the agricultural sector, the impact of climate change can shift planting patterns and times and cause pest and disease outbreaks (Sujarwo, 2023).

Mitigation and adaptation strategies in the agricultural sector related to climate change, especially the variability of rainfall that occurs, are needed to maintain agricultural productivity. Given the uncertain climate conditions, adaptation patterns can no longer be carried out by relying on seasonal patterns as before (Yulianto and Sudibyakto, 2012). Mitigation and adaptation to climate change contained in the Regulation of the Minister of Agriculture of the Republic of Indonesia in 2018 concerning the Early Warning System and Handling of the Impact of Climate Change on the Agricultural Sector Article 10, such as can apply water harvesting technology, such as utilizing reservoirs and long storage to collect rainwater that can be used in the dry season and implementing Integrated Pest Control to minimize rice plants being attacked by pests and diseases in the rainy season.

IV. CONCLUSION

1. Rainfall projections until 2045 in the two study areas of Malang and Banyuwangi regencies, in the RCP 2.6 scenario, show an increase in rainfall in several months but still maintain a relatively stable rainfall pattern and intensity, with peak rainfall in the early months of the rainy season and decreased rainfall during the dry season. Meanwhile, the RCP 8.5 scenario shows more extreme rainfall variations and greater fluctuations between wet and dry months, indicating a drier dry season and a wetter rainy season in the future.
2. Projections of rice productivity until 2045, in the RCP 2.6 scenario, show an increase in rice crop productivity in 2045, while the RCP 8.5 scenario shows a decrease in rice crop productivity in 2045 in Malang and Banyuwangi regencies. Despite the decline, the projected results of rice crop productivity obtained in Malang and Banyuwangi regencies, namely 7.83 tons ha^{-1} and 6.85 tons ha^{-1} or still exceeding the target estimated by the Republic of Indonesia government of 5.90 tons ha^{-1}

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