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Impact of Climate Variation on Potato (*Solanum tuberosum* L.) based on Climate Projections until 2100

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Abstract— One of the challenges faced in cultivating potatoes is global warming, which has the potential to result in an increase in atmospheric temperatures, as well as changes in various climate variabilities that can affect the planting season, growth, and crop yields. This research aims to project an increase in atmospheric temperature until 2100 in two production center areas based on climate projection models in three Representative Concentration Pathways (RCP) scenarios, as well as projecting potato crop productivity in these two locations based on climate projection results. This research was carried out by examining climate variations at two location points, namely Tosari District and Poncokusumo District, and was conducted in May-October 2023. The tools used in this research included Microsoft Excel 2013, CORDEX, ArcMap 10.8, and NASA POWER software. The materials used include historical data on daily rainfall, daily minimum temperature, and daily maximum temperature, as well as potato productivity data from Tosari District and Poncokusumo District. Data analysis carried out in this research consisted of: 1) validation test of the climate projection model used, 2) projection of average rainfall and temperature, 3) multiple linear regression analysis to project potato crop productivity. The research results show that in the RCP 2.6 scenario, there is no pattern of increase in average atmospheric temperature until 2100, while there is a pattern of temperature increase of 0.41-1.21°C and 1.26-2.23°C in the RCP 4.5 scenario and RCP 8.5. There is an increase in potato plant productivity in Tosari District and Poncokusumo District based on productivity projections until 2100. Meanwhile, there is a decrease in potato plant productivity in Poncokusumo District in the RCP 2.6 and RCP 4.5 scenarios. Based on the RCP 8.5 scenario, there is a pattern of higher productivity increase in Poncokusumo District compared to Tosari District.

*Keywords***— *Climate Projection, Potatoes, Productivity, RCP***

I. INTRODUCTION

Potatoes (*Solanum tuberosum* L.) are one of the horticultural commodities that serve as an alternative carbohydrate source and are needed by society as one of the essential food ingredients. Along with the increasing population in Indonesia, the demand for potatoes in society continues to increase. In 2022, the demand for potatoes reached 874.25 thousand tons (an increase of about 13.32% compared to the previous year) (Irijayanti et al., 2023). The increasing demand for potatoes in society is also accompanied by an increase in the volume of fresh potato imports from several countries, such as Belgium, the United States, and the Netherlands. The volume of fresh potato imports in Indonesia was 40,493 tons in 2020, 52,286 tons in 2021, and 74,438 tons in 2022. Meanwhile, the volume of fresh potato exports continues to decline. The volume of fresh potato exports in Indonesia was 4,357 tons in 2020, 3,121 tons in 2021, and 2,666 tons in 2022. This indicates that there is a domestic challenge to increase potato crop productivity in order to reduce the volume of potato imports from abroad so that the needs of the people can be met.

East Java Province is the province with the highest contribution to potato production in Indonesia. In 2022, East Java had a production of 385.12 thousand tons, which is about 25.61% of the total production of potatoes on a national scale (Irijayanti et al., 2023). The potato cultivation center areas in East Java are located in several districts, two of which are Pasuruan District and Malang District. Tosari Sub-district is a production center area in Pasuruan District with a production reaching 1,542,806 quintals in September 2020 (Pasuruan District Central Statistics Agency, 2022). Poncokusumo Sub-district is a production center area in Malang District with a production reaching 252,080 quintals in 2020 (Malang District Central Statistics Agency, 2022).

One of the challenges faced in potato cultivation is global warming. This phenomenon is caused by an increase in greenhouse gas emissions in the atmosphere originating from various human activities. These gases can trap solar heat in the atmosphere, causing the air temperature to rise and affecting climate variations. This has the potential to result in shifting weather patterns and increasing atmospheric temperatures that can affect changes in planting seasons and agricultural production.

Potatoes are sensitive to high temperatures, and temperature stress can significantly reduce potato yields (Singh et al., 2020). Temperature stress can inhibit seedling growth, leaf formation, and quality tuber formation. Changes in rainfall patterns within a year can affect the optimal planting season for potato growth. Thus, appropriate adaptation strategies based on the analysis of possible climate variations in the coming years are needed to maintain and strengthen potato crop productivity.

The process of predicting and identifying climates in the future currently uses climate projection models that have been developed in various countries. Climate projection models are models developed to simulate the atmosphere, ocean, ice, and land to obtain outputs in the form of information on the extent of human activity's influence on the climate (Akbar et al., 2022). This modeling has been utilized and developed to estimate climate events in the future and analyze their causes by simulating historical data. The use of climate projections can be applied in various fields, including agriculture.

The application of climate projections is done by simulating scenarios of greenhouse gas emissions in the atmosphere with projections of radiation on different scales. These scenarios are called Representative Concentration Pathways (RCP). There are four different RCP scenarios, namely RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5 (Rao et al., 2020). These four scenarios are projected based on trends and the possibility of tightness or looseness of climate change mitigation measures implemented in a region. RCP 2.6 is a scenario of strict climate change mitigation, RCP 4.5 and 6.0 are moderate scenarios, and RCP 8.5 is a scenario with very high greenhouse gas concentrations (Bienvenido-Huertas et al., 2021).

This research was conducted to project climate variations until 2100 in potato production center areas, namely Tosari and Poncokusumo Sub-districts. Climate projections were carried out using Global Climate Models (GCM) based on three different Representative Consentration Pathways scenarios on different scales, namely RCP 2.6 (low scale), RCP 4.5 (medium scale), and RCP 8.5 (high scale). This prediction was made to analyze the impact of climate variations on three emission scenarios and concentrations of greenhouse gases on potato crop productivity so that it can be considered for the development of potato cultivation strategies in the future.

II. MATERIALS AND METHODS

This study investigates the impact of climate variations on potato crop productivity in two research areas, which are the central potato production areas in East Java, namely Tosari Sub-district, Pasuruan Regency, and Poncokusumo Sub-district, Malang Regency. The coordinates of Tosari Sub-district are 7.889844 South Latitude and 112.924890 East Longitude. The coordinates of Poncokusumo Sub-district are 7.9860258 South Latitude and 112.9110814 East Longitude. Both areas have highland topography. The research was conducted from May to October 2023.

The tools used in this study included Microsoft Excel 2013 software, Coordinated Regional Climate Downscaling Experiment (CORDEX), ArcMAP 10.8, and NASA Prediction Of Worldwide Energy Resources (NASA POWER). The materials used in this study consisted of historical climate data, including daily rainfall, daily minimum temperature, and daily maximum temperature for the last 30 years, as well as potato production data from Tosari Sub-district and Poncokusumo Sub-district from 2018 to 2021.

This research projected climate variations at observation points until 2100 based on a comparison of three different climate projection models (CNRM-CM5, HadGEM2-ES, and MPI-ESM-LR). The study comprised data collection, climate projection, bias correction validation, classification of climate variation trends, and projection of potato productivity using multiple linear regression analysis.

HASIL DAN PEMBAHASAN

Historical Climate Observation Data

Historical climate observation data in both study areas show differences in rainfall and temperature. In the Tosari District, the highest average rainfall peak occurs in

January (691.818 mm/month) and the lowest rainfall is recorded in September (37.232 mm/month). Tosari District experiences wet months from November to May, moist months in June and October, and dry months from July to September. In the Poncokusumo District, the highest rainfall peak is in February (343.583 mm/month) and the lowest is in August (21.361 mm/month). Poncokusumo District experiences wet months from November to March, moist months in April and October, and dry months from May to September. Based on the conversion results of maximum and minimum temperatures, both observation areas have the highest average maximum temperature peak per month in October and the lowest minimum temperature in August. The average maximum temperature throughout the year in Tosari District is 19.219°C and in Poncokusumo District is 18.93°C. Meanwhile, the average minimum temperature throughout the year in Tosari District is 10.91°C and in Poncokusumo District is 10.36°C.

In the Tosari District, the average annual rainfall is 4115.63 mm/year. Meanwhile, in the Poncokusumo District, the average annual rainfall is 2024.15 mm/year. Based on the average rainfall in both locations, the Tosari District has higher rainfall compared to the Poncokusumo District. The primary factor influencing rainfall in an area is the sea surface temperature anomalies in the equatorial Pacific Ocean caused by the ENSO (El Nino Southern Oscillation) phenomenon (Somadayo *et al*., 2022). This phenomenon is a global interaction between the ocean and atmosphere consisting of two main phases, El Niño and La Niña. During the El Niño phase, there is a rise in sea surface temperatures accompanied by decreased rainfall and increased air temperatures in Indonesia. During the La Niña phase, there is a decrease in sea surface temperatures leading to increased rainfall and decreased air temperatures in Indonesia. This affects various climate factors such as wind patterns, atmospheric pressure, humidity, temperature, and rainfall distribution.

Both study areas have characteristics of monsoon rainfall. This is characterized by distinct differences between the rainy season and dry season periods, and is characterized by only one peak in rainfall within a year. In the Tosari District, the rainy season occurs from November to May and the dry season from June to October. In the Poncokusumo District, the rainy season occurs from November to April and the dry season from May to October. The characteristics of monsoon rainfall are influenced by monsoon winds driven by high-pressure cells and low-pressure cells in Asia and Australia that alternate (Tukidi, 2010).

Based on data observation analysis, the differences in rainfall are also influenced by topographic factors. Both study areas are mountainous regions, leading to the presence of orographic effects that affect rainfall patterns. Mountain ranges or hills can act as physical barriers affecting wind movement. Topographic barriers consist of two different sides: the windward side and the leeward side. On the windward side, moist air coming from the sea or lowlands is pushed upwards due to the presence of mountains. The rising air cools and undergoes condensation processes. On the leeward side, air that has lost moisture descends to lower elevations. Therefore, rainfall on the windward side is high, while on the leeward side it is low. The leeward side is the rain shadow side because it has drier conditions.

The Tosari District experiences the highest rainfall in January with 691.818 mm/month, while the Poncokusumo District experiences the highest rainfall in February with 343.583 mm/month. This indicates that the maximum rainfall in the Tosari District is more than twice as high as in the Poncokusumo District. This is because the Tosari District is a mountainous area closer to the monsoon winds on the northern coast of Java Island, making it the windward side. Meanwhile, the Poncokusumo District is on the leeward side, resulting in lower rainfall. Although the Poncokusumo District is closer to the southern coast, based on rainfall observation data, it can be concluded that stronger winds are present on the coast closer to the Tosari District.

Climate Model Validation Test

Based on the validation test results of the three climate models, climate determination is conducted based on the lowest RMSE values for each observation variable. The selection of the best climate GCM model for each variable can be seen in Tables 1 and 2. RMSE values approaching zero (0) indicate high data closeness to historical data.

Table 1. Selection of GCM for Climate Projections in Tosari District

Variabel	Scenario	Selected GCM	RMSE
Rainfall	RCP 2.6	MPI-ESM-LR	23,54
	RCP 4.5	HadGEM2-ES	4,12
	RCP 8.5	HadGEM2-ES	11,25
Maximum Temperature	RCP 2.6	MPI-ESM-LR	6,16
	RCP 4.5	MPI-ESM-LR	1,86
	RCP 8.5	MPI-ESM-LR	0,54
Minimum Temperature	RCP 2.6	MPI-ESM-LR	32,28
	RCP 4.5	MPI-ESM-LR	33,96
	RCP 8.5	MPI-ESM-LR	34,83

Description:

RMSE : *Root Mean Square Error*

Table 2. Selection of GCM for Climate Projections in Poncokusumo District

Variabel	Scenario	Selected GCM	RMSE
Rainfall	RCP 2.6	HadGEM2-ES	27,85
	RCP 4.5	CNRM-CM5	23,27
	RCP 8.5	CNRM-CM5	36,41
Maximum Temperature	RCP 2.6	HadGEM2-ES	47,54
	RCP 4.5	MPI-ESM-LR	46,41
	RCP 8.5	MPI-ESM-LR	44,11
Minimum Temperature	RCP 2.6	MPI-ESM-LR	8,94
	RCP 4.5	MPI-ESM-LR	10,50
	RCP 8.5	HadGEM2-ES	10,49

Description:

RMSE : *Root Mean Square Error*

Rainfall and Temperature Projections

Rainfall and temperature projections are carried out using Global Climate Models to compare climate variations in three different greenhouse gas concentration scenarios, namely RCP 2.6 (low level), RCP 4.5 (medium level), and RCP 8.5 (high level). Projections are made by multiplying data from climate models by monthly correction factors for each study area. Figures 1-6 depict rainfall projections in both study areas for the periods 2021-2040, 2041-2060, 2061-2080, and 2081-2100.

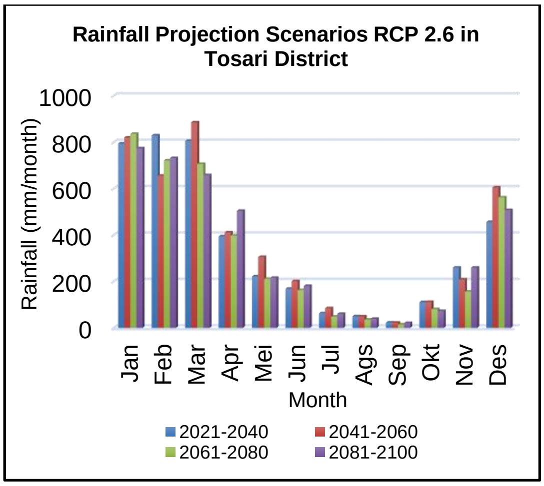

Fig.1. Rainfall Projection Scenario RCP 2.6 in Tosari District

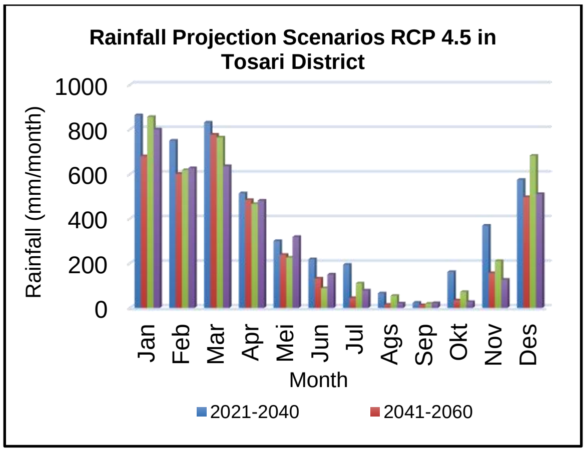

Fig.2. Rainfall Projection Scenario RCP 4.5 in Tosari District

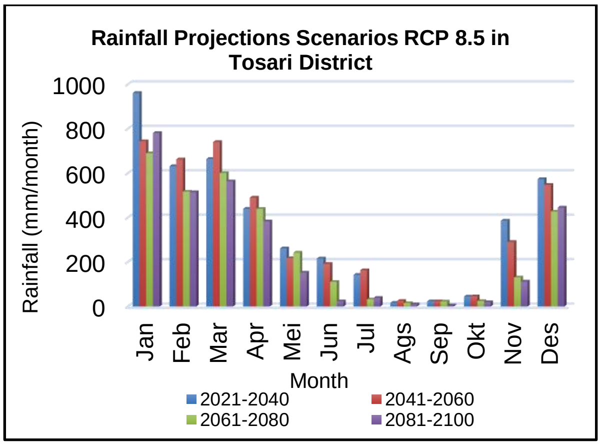

Fig.3. Rainfall Projection Scenario RCP 8.5 in Tosari District

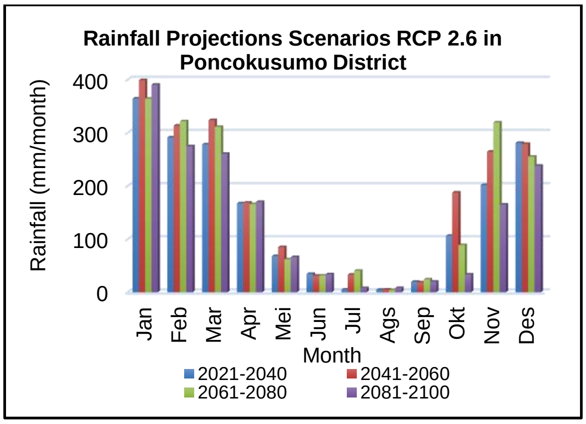

Fig.4. Rainfall Projection Scenario RCP 2.6 in Poncokusumo District

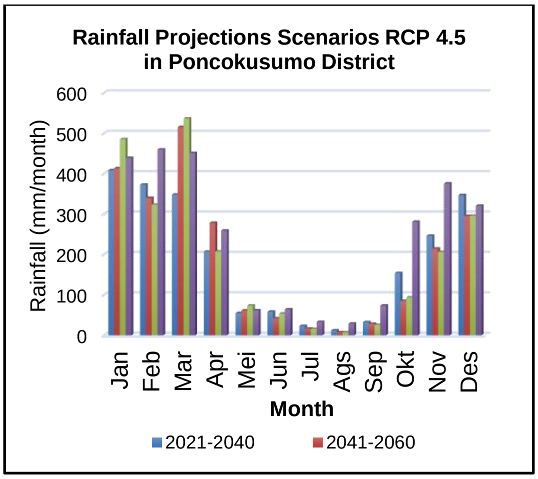

Fig.5. Rainfall Projections Scenarios RCP 4.5 in Poncokusumo District

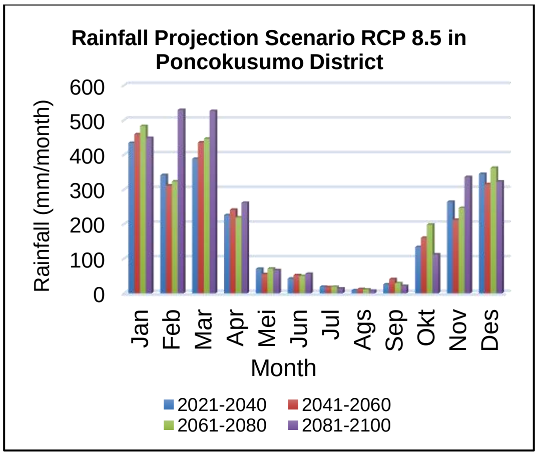

Fig.6. Rainfall Projection Scenario RCP 8.5 in Poncokusumo District

Temperature projections are also conducted by multiplying the maximum and minimum temperature data for each climate model by monthly correction factors for each study area. Figures 7 and 8 show the projection of maximum temperature in the study areas based on three climate projection scenarios, while Figures 9 and 10 show the projection of minimum temperature based on three climate projection scenarios.

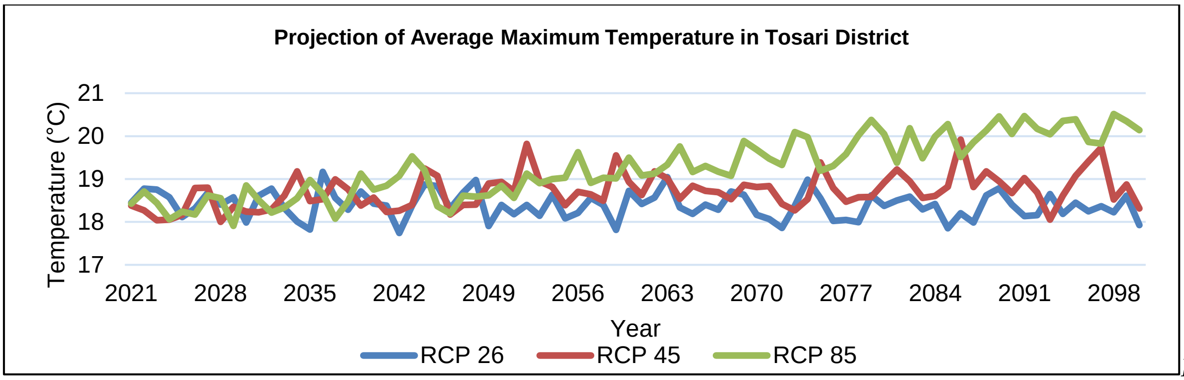

Fig.7. Projection of Monthly Average Maximum Temperature in Tosari District

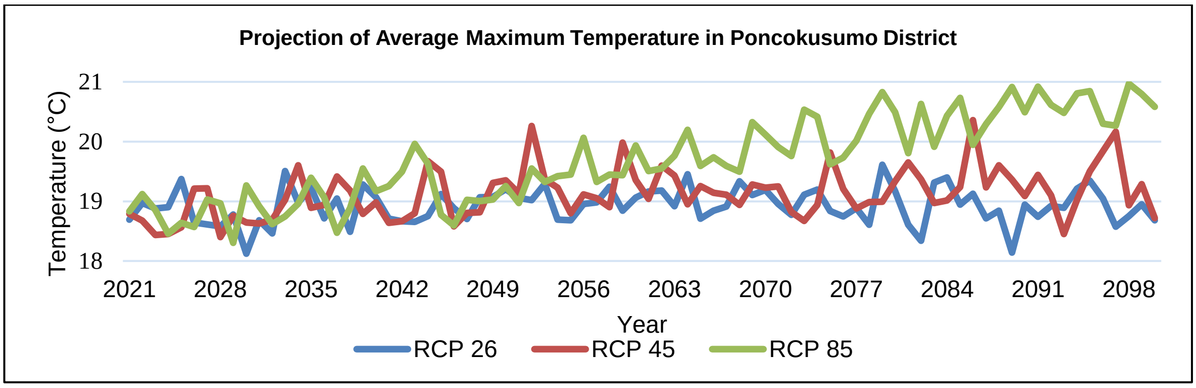

Fig.8. Projection of Monthly Average Maximum Temperature in Poncokusumo District

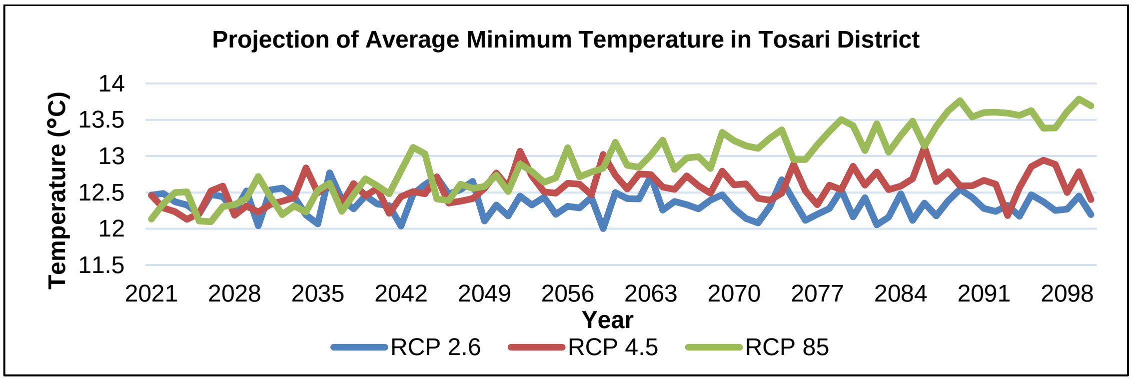

Fig.9. Projection of Monthly Average Minimum Temperature in Tosari District

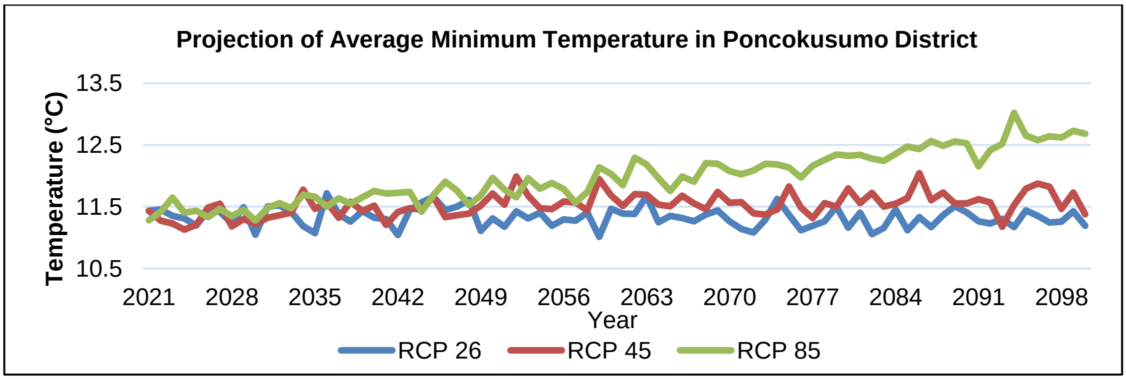

Fig.10. Projection of Monthly Average Minimum Temperature in Poncokusumo District

Based on the projections, greenhouse gas emissions and concentrations in the atmosphere affect climate variability based on rainfall and temperature variables in the study areas. Changes become more significant in scenarios with higher emissions and greenhouse gas concentrations, as indicated by the comparison of projections based on RCP scenarios. In the RCP 8.5 scenario, changes in the rainy and summer seasons in both areas occur earlier compared to the RCP 2.6 and RCP 4.5 scenarios. This is shown by changes in the transition between wet and dry months. With higher emissions and greenhouse gas concentrations scenarios, climate variability projections are also accompanied by more significant increases in both maximum and minimum temperatures. In the RCP 8.5 scenario, temperature increases in both study areas are higher compared to the RCP 2.6 and RCP 4.5 scenarios. The annual average temperature increase in the RCP 8.5 scenario until 2100 can reach 1.26-2.23°C. Meanwhile, in the RCP 4.5 scenario, it can only reach 0.41-1.21°C, and in the RCP 2.6 scenario, there are no significant temperature variations. The months with the highest maximum and minimum temperatures in a year experience temperature increases of 1.16-2.67°C in the RCP 8.5 scenario, while in the RCP 4.5 scenario, they experience increases of 0.29-1.44°C.

The three climate variability scenarios used to project climate in this study depict differences in emission assumptions and the stringency of mitigation measures against greenhouse gas emissions. Greenhouse gases included in these projection models include carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), sulfur dioxide (SOx), carbon monoxide (CO), non-methane volatile organic compounds (NMVOCs), nitrogen oxides (NOx), black carbon (BC), organic carbon (OC), and ammonia (NH3) (Meinshausen et al., 2011). The RCP 2.6 scenario is a very stringent mitigation scenario, assuming constant emissions and CO2 concentrations returning to 360 ppm by 2300. Therefore, climate variability in the RCP 2.6 scenario represents a scenario projecting stable climate variability over the long term. The RCP 4.5 scenario is a moderate mitigation scenario, reaching its peak in 2040 and then declining, stabilizing CO2 at around 540 ppm by 2100. In the RCP 8.5 scenario, there are no significant efforts to mitigate greenhouse gases, so emissions and greenhouse gas concentrations are assumed to increase throughout the 21st century. This scenario assumes a CO2 concentration of 1370 ppm by 2100. Thus, each RCP scenario has a different rate of emissions increase over the period up to 2100.

The level of greenhouse gas emissions affects the radiative forcing value, which represents the radiative energy entering and leaving the Earth's atmosphere. A positive radiative forcing value indicates that more energy enters the atmosphere than leaves it due to high greenhouse gas emissions. In the RCP 8.5 scenario, the atmosphere has an estimated radiative forcing value of 8.5 W/m² by 2100, and this radiative forcing value is the highest compared to the RCP 2.6 and RCP 4.5 scenarios (van Vuuren *et al.*, 2011). This affects the impacts on climate variability in the study areas. Radiation leads to an increase in average temperatures both in the ocean and on land, and affects rainfall patterns in the study areas. In the temperature projection results, temperature increases in the RCP 8.5 scenario are higher compared to the other scenarios.

Potato Crop Productivity Projection Results

Multiple linear regression analysis was conducted to determine the relationship between potato crop productivity and two climate variables in both study areas, namely rainfall and temperature. Potato crop productivity in the Tosari District has a regression equation Y = 5.58947 - 0.00395 x1 + 3.13113 x2, and potato crop productivity in the Poncokusumo District has a regression equation Y = -105.235 - 0.00253x1 + 8.66131x2 (Y is the potato crop productivity in the Poncokusumo District, x1 is the average annual rainfall value, and x2 is the average annual temperature in the study areas). These equations are used to determine the projected values of potato crop productivity until 2100 (Figures 11 and 12; Tables 3 and 4).

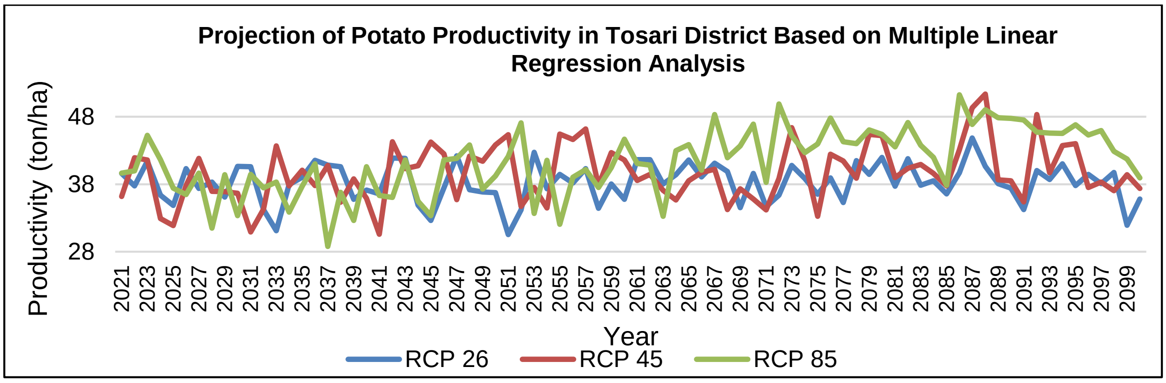

Fig.11. Projection of Potato Crop Productivity in Tosari District Based on Multiple Linear Regression Analysis

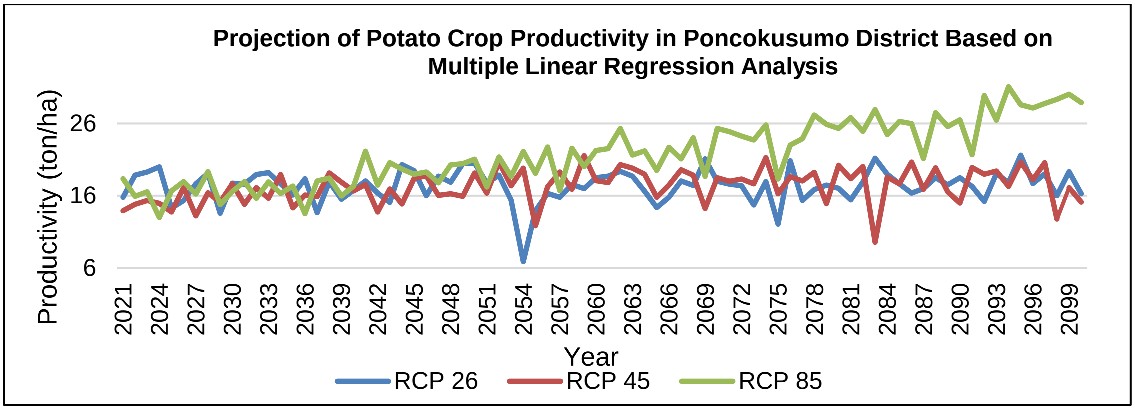

Fig.12. Projection of Potato Crop Productivity in Poncokusumo District Based on Multiple Linear Regression Analysis

Table 3. Projection of Average Potato Crop Productivity in Tosari District

Year	RCP 2.6		RCP 4.5		RCP 8.5	
	Projection (ton/ha)	**Increase/ Decrease Based on Baseline**	**Projection (ton/ha)**	**Increase/ Decrease Based on Baseline**	**Projection (ton/ha)**	**Increase/ Decrease Based on Baseline**
2021-2040	38,072	10,00%	37,491	8,32%	37,550	8,49%
2041-2060	37,455	8.22%	40,803	17,90%	39,239	13,37%
2061-2080	39,041	12,80%	39,198	13,26%	43,517	25,74%
2081-2100	38,490	11,21%	40,968	18,37%	45,144	30,44%

Table 4. Projection of Average Potato Crop Productivity in Poncokusumo District

Year	RCP 2.6		RCP 4.5		RCP 8.5	
	Projection (ton/ha)	**Increase/ Decrease Based on Baseline**	**Projection (ton/ha)**	**Kenaikan/ Penurunan Berdasarkan *Baseline***	**Projection (ton/ha)**	**Increase/ Decrease Based on Baseline**
2021-2040	17,165	-3,03,%	15,945	-9,92%	16,698	-5,67%
2041-2060	17,039	-3,74%	17,343	-2,02%	20,027	13,14%
2061-2080	17,276	-2,40%	18,198	2,81%	23,266	31,44%
2081-2100	17,916	1,21%	17,664	-0,21%	26,997	52,52%

Projection of average annual potato crop productivity based on multiple linear regression analysis shows the different climate variability impacts in the two study areas. Tosari District projects an increase in average annual potato crop productivity in scenarios RCP 2.6, RCP 4.5, and RCP 8.5. Scenario RCP 8.5 experiences a significant increase pattern with an average increase of 6.91% every 20 years until 2100. Meanwhile, the average annual potato crop productivity in Poncokusumo District experiences a long-term decrease in average potato crop productivity in scenarios RCP 2.6 and RCP 4.5. Productivity projections based on scenario RCP 8.5 show a significant increase pattern with an average increase of 17.38% every 20 years until 2100. This indicates that: 1) there is an influence of increasing greenhouse gas concentrations and emissions on potato crop productivity in a region, 2) geographic location plays a role in supporting future potato crop productivity based on climate factors, particularly regarding temperature and rainfall projections.

Based on the research findings, the increase in average annual temperature due to increasing greenhouse gas emissions is directly proportional to the potato crop productivity projections in both regions. This is indicated by the average annual potato crop productivity showing an increasing trend in the RCP 8.5 scenario, while fluctuations occur in the RCP 2.6 and RCP 4.5 scenarios. This phenomenon is consistent with the research conducted by Jennings et al. (2020), which suggests a potential increase in potato productivity globally due to global warming. This is because the increase in atmospheric CO2 can enhance carbon dioxide fertilization in potato plants, potentially increasing productivity by 22-33%. Atmospheric carbon dioxide is an essential component for plants in carrying out the process of photosynthesis. The accumulated carbohydrates produced from photosynthesis are used for plant growth and tuber formation, thus potentially increasing yields.

Geographic location is also one of the factors influencing potato crop productivity projections. Based on the previous observational data analysis, Tosari District is the windward side facing the sea experiencing monsoon winds, while Poncokusumo District is the leeward side opposite the direction of the wind. With the RCP 8.5 scenario, the average annual potato crop productivity on the leeward side is projected to experience a higher percentage increase in productivity compared to the windward side until 2100. The leeward side is a relatively drier area compared to the windward side, and the high greenhouse gas emissions scenario has the potential to increase rainfall in that area and can increase soil moisture (Kagawa-Viviani et al., 2018). This is consistent with climate projection results showing that Poncokusumo District has increased rainfall until 2100 in the RCP 8.5 scenario. Meanwhile, climate projections show that Tosari District, which has wetter conditions, experiences decreased rainfall until 2100 in the RCP 8.5 scenario. However, overall potato crop productivity in Tosari District remains higher in all three climate projection scenarios. This is because Tosari District has higher observed and projected rainfall compared to Poncokusumo District. Tosari District has rainfall of 4115.65 mm/year based on observational data, and projections show a decrease in rainfall to 3049.08 mm/year in the RCP 8.5 scenario. Meanwhile, Poncokusumo District has rainfall of 2024.15 mm/year based on observational data, and projections show an increase in rainfall to 2847.32 mm/year.

When viewed based on atmospheric temperature, the projected atmospheric temperatures in both areas in the RCP 8.5 scenario are suitable for the cardinal temperature of potato plants. According to Singh et al. (2013), the optimum cardinal temperature for potato plants ranges from 16-25°C. With the suitability of the optimum cardinal temperature, the processes of photosynthesis and transpiration in potato plants can proceed smoothly, resulting in optimal plant development. If the temperature is too high, it can delay tuber initiation and affect potato crop productivity and tuber quality. These conditions have the potential to damage potato plants.

The impact of climate variability on potato growth and productivity is complex, so increasing atmospheric greenhouse gas emissions can affect productivity both positively and negatively. The impact depends on factors related to supporting components of potato growth, such as atmospheric temperature and rainfall. Temperature plays a crucial role in supporting each phase of potato plant growth. High atmospheric temperatures accelerate evapotranspiration, causing water stress for plants due to water loss. This condition can affect potato plant growth in several phases, such as tuber formation and maturation. If the tuber formation and maturation processes are not optimal, it can lead to yield reduction. Additionally, global warming affects rainfall distribution in a region and triggers increased extreme weather. Extreme dry weather can cause soil moisture to be insufficient for potato plants to perform photosynthesis and form good tubers. Meanwhile, excessive rainfall can also cause soil erosion, leading to a lack of soil fertility for potato growth and development. To adapt to extreme weather changes, adaptive measures can be taken by planting potatoes earlier to avoid extreme dry weather disasters (Zhao and Li, 2015). This step has the potential to increase yields.

The response of potato crop productivity to increased greenhouse gas emissions can vary. Farming practices that can adapt to climate change and the implementation of policies tailored to regional conditions are essential. Based on the research conducted, greenhouse gas emissions affect rainfall distribution in a region, leading to different projections in different areas. Therefore, appropriate water management measures are needed to maintain optimal potato crop productivity. Water management for potato cultivation can be carried out by regulating proper irrigation, efficient water usage, and good rainwater management (Pratama et al., 2021). Irrigation and drainage systems, in adhering to water management principles, can utilize suitable technologies. Efficient irrigation technologies such as drip irrigation or sprinklers with proper irrigation scheduling can be employed. Drainage management can also be achieved by regulating drainage channels to function effectively in preventing potato plants from being waterlogged.

III. CONCLUSION

In the RCP 2.6 scenario, there is no pattern of average atmospheric temperature increase until 2100. In scenarios RCP 4.5 and RCP 8.5, there is a temperature increase pattern of 0.41-1.21°C and 1.26-2.23°C, respectively. The temperature increase in Tosari District is potentially higher than in Poncokusumo District. Based on productivity projections, there is an increase in potato crop productivity in both Tosari and Poncokusumo Districts based on productivity projections until 2100. Meanwhile, there is a decrease in potato crop productivity in Poncokusumo District in scenarios RCP 2.6 and RCP 4.5. According to the RCP 8.5 scenario, there is a higher productivity increase pattern in Poncokusumo District compared to Tosari District.

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