Climate Change and Rice Production in East Java Province, Indonesia

Mutiarra Ridyo Arum(✉), Arini Wahyu Utami, and Irham Irham

Department of Agriculture Socioeconomics, Faculty of Agriculture, Universitas Gadjah Mada, Yogyakarta, Indonesia
mutiarra.ridyo.arum@mail.ugm.ac.id

Abstract. Rice is an important food commodity in Indonesia and several other developing countries, making its increase in demand in line with the population growth. While the government devise policies that attempt to boost rice production, limited resources, changing natural conditions and human activities impose challenges in this endeavor. Agriculture is a sector that is vulnerable to the risk of failure and economic loss from climate change, as measures, among other, in the changes and variability of temperature and rainfall. Hence, this study aims to describe the temperature and rainfall changes and variability, or we term climate change, as well as to assess the relationship between climate change and rice production in East Java Province. We collected data of monthly and annual temperature, rainfall, and rice production of East Java from 1981 to 2018 (38 years) from the Bureau of Meteorology, Climatology, and Geophysics (*Badan Meteorologi Klimatologi dan Geofisika*, BMKG) and the Bureau of Statistics (*Badan Pusat Statistik*, BPS). The results show that there are increases in 1981–2018 monthly average, minimum, and maximum temperature, where (2001–2018) period experienced higher monthly temperature than the previous one (1981–2000). The differences between the two periods are also statistically significant. Meanwhile, rainfall in both periods is not statistically different, although rainfall in 2001–2018 tend to be higher than those in 1981–2000. Consequently, despite increasing trend in East Java's annual rice production from 1981 to 2018, the period of 2001–2018 show that rice production is as fluctuated as the rainfall, average, minimum and maximum temperatures.

Keywords: Climate change · rice production · temperature · rainfall · east java

1 Introduction

Industrialization and growing dependence on fossil fuels have led to an increase in the concentration of greenhouse gases in the atmosphere, such as CO_2, N_2O and CH_4. This led to an increase in air temperature at the end of the nineteenth century by 0.85 °C. Intergovernmental Panel on Climate Change (IPCC) predicts that in 2100 there will be an increase in global temperature of 1.8 °C to 4.08 °C [1], while the threshold for temperature for temperature increase is 2 °C. The occurrence of climate change has an

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impact on changes in temperature, frequency of rainfall, solar radiation, wind, humidity, and the hydrological cycle.

The increase in the global population is estimated to reach 9.7 billion by 2050 and occurs in almost all developing countries [2]. The increase in the world's population pushes toward higher global demand for foods, including rice. Indonesia has the highest level of rice consumption in the world, with an average consumption of rice reaching 1.569 kg/capital/week [3]. As a crucial commodity that support food security, the Indonesia government implements policies intended to improve rice production. It is estimated that the increase in food crops production globally reached 100–110% [4].

However, Indonesia's geographical location add challenges on this attempt to boost rice production. Being situated on the equator and between two oceans affect Indonesia's dynamic climate patterns, which consequently entices the occurrence of extreme weather that cases changes in rainfall, significant increases in temperature and sea level [5]. In other words, Indonesia's agriculture sector has become more vulnerable to climate change.

Climate change affects human activities. Based on the potential economic losses from the impacts of climate change, the Indonesia government focuses on the four sectors that will be significantly affected, namely marine and fisheries water sector, agriculture, and health sectors [6]. The agricultural sector is projected to receive the largest potential economic loss in Indonesia by 2024. The economic loss may come from decline in food crop production due to changes in temperature. The Indonesia's National Agency for Development Planning *(Badan Perencanaan Pembangunan Nasional,* BAPPENAS) reported that the potential loss from a decrease in rice production will be more that 25% and economic losses will reach IDR 19.4 trillion in 2024 [6].

Facing potential losses from climate change in the agriculture sector the Indonesia's government created categorization of climate change impact by location based on seven components, i.e., Climate Projection, Hazard Potential, Information System Data in Vulnerability Index *(Sistem Informasi Data Indeks Kerentanan,* SIDIK*),* Indonesia's Disaster Risk Index *(Indeks Risiko Bencana Indonesia,* IRBI*),* Economic Loss Potential, Ministries and Institutions Proposals *(Usulan Kementerian dan Lembaga),* and Field Validation [7]. The regencies are classified into three categories of climate change impact: super priority, top priority, and priority. Figure 1 shows that East Jaca Province has 19 super priority locations exceeding other provinces in Java and Bali, making it the most vulnerable province to climate change. In addition to the fact that East Java is an important rice producer in Indonesia, study of the relationship between climate change and rice production in East Java becomes increasingly crucial to do. In this study, we limit the discussion of climate change on the variability and change in climatic factors of rainfall and temperature only.

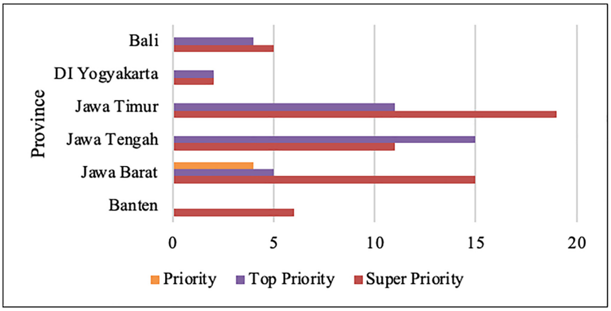

Fig. 1. Classification of Climate Change Vulnerability by Location in Java and Bali.

2 Literature Review

2.1 Climate Change

Climate is an average value of atmospheric conditions over a long period in a particular area, while weather is changes in those atmospheric conditions in a relatively short time duration. The average state of the weather elements over a long period of time is a description of the climatic conditions in the area. Climate change is a change in the pattern of the intensity of climate elements. The occurrence of climate change can be seen from changes in climatic parameters more extreme.

Climate change is happening globally, but the perceived impact varies locally is site-specific. According to [8], there are four indicators as measure of climate change and its impact in Indonesia, including changes in land temperature, increase extreme rainfall, seasonal changes and changes in the volume of rain. With the increasing rainfall variability due to climate change, the risk of hydrological disasters, such as floods, reduced water availability, and droughts, have also been increasing. Extreme temperature from climate change also induces higher rate of evapotranspiration. Consequently, floods, droughts, as well as the rapid evapotranspiration affect the stages of plant growth, e.g., flowering, pollination, and grain filling stages [9].

2.2 Optimal Conditions for Rice Production

Biologically, rice plant can grow at an altitude of 0–1,500 m, with optimum temperature of 23 °C to 35 °C [10] and requires seasonal rainfall of approximately 300–500 mm [11]. If rice is grown on dry land with rainfed irrigation, it requires higher rainfall of 1,000 mm. Research conducted [12] revealed that temperatures above 34 °C can interfere with plant growth. On the other hand, [13] states that lower temperatures than usual can reduce crop yields since plant growth is dependent on temperature Some non-climatic factors that affect rice productivity include seeds, labor, fertilizers, and pesticides. In pre-planting activities, farmers carry out tillage and irrigation to increase soil moisture. Furthermore, in seedling and rice planting activities, farmers consider planting time to ensure the availability of water in farming activities. Adequacy of water is the main factor of success in the vegetative growth period of rice.

Drier condition with insufficient water causes rice plants to be drought stress, which interferes with the photosynthesis process. The photosynthesis includes a crucial chemical process where the water is needed for rice plant to produce sugar and carbohydrates to fill rice panicles. Respiration is another important mechanism that is involved in the growth stage of rice plant, where biomass is converted into roots, stems, leaves, and panicles. The optimal minimum temperature of rice is around 22 °C, where lower or higher temperature than that will interfere with respiration process, and consequently, impacting the rice production [14]. In addition to heat stress, exposure to cold stress during rice growth influences the formation of mass, causing panicle sterility, inhibits grain formation, affects grain quality, and lower production yields [15].

The rice growth process consists of three stages, namely the vegetative, reproductive, and maturation stages. In the vegetative phase, rice can experience chloroplast damage if the maximum temperature exceeds the temperature threshold [10]. However, at this stage, rice is relatively tolerant of higher temperatures, compared to other stages. Vulnerability that may occur in the reproductive stage is grain sterility when rice is continuously exposed to high temperatures. At the ripening stage, rice may experience a lower grain weight and a shorter grain filling period, leading to lower yields.

3 Methodology

We collected monthly rainfall and average, minimum, and maximum temperature data of 1981–2018 (38 years) from the Bureau of Meteorology, Climatology, and Geophysics (*Badan Metorologi Klimatologi dan Geofisika*, BMKG), more specifically from Juanda Meteorological Station, Sidoarjo, and annual rice production data of 1981–2018 from the Bureau of Statistics (*Badan Pusat Statistik*, BPS) of East Java Province. We selected the Juanda Meteorological Station due to its good continual operation of its weather station equipment, resulting in complete data, in addition to minimum non-meteorological, external disturbances [16]. We divided the climate data into two periods, namely the baseline period of 1981–2000 (20 years or two decades) and the current period of 2001–2018 (18 years). Besides analyzing the data graphically, we also tested the difference between the decades (1981–2000 vs. 2001–2018) by using Mann-Whitney and Levene statistical test [17]. As to assess the relationship between rainfall and temperature with annual rice production, we relied more on descriptive analysis by using graphical method.

4 Results and Discussion

4.1 Climate Change in East Java

Annually rainfall of the East Java Province did not experience significant changes from the baseline (1981–2000) to the current period (2001–2018). The average annual rainfall for the baseline period (1981–2000) was 2,044 ± 603 mm/year, only slightly lower than the current period (2001–2018), i.e., 2,117 ± 117 mm/year. We tested the rainfall difference between the two periods and found no statistically significant difference (sig. $t\ (38) = 0.520 > a = 0.05$). However, annual temperature was statistically significant different between 1981–2000 and 2001–2018 (sig. $t\ (38) = 0.02 < a = 0.05$). This indicates an increase in annual temperature variability, both the average temperature, minimum temperature, and maximum temperature in East Java Province.

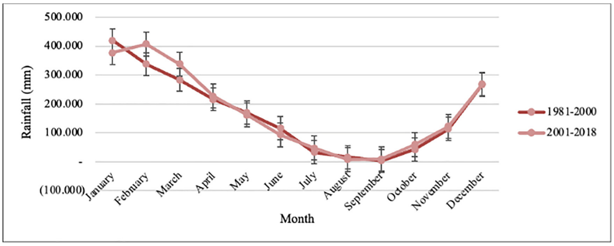

Fig. 2. Monthly rainfall in the baseline (1981–2000) and current period (2001–2018).

4.1.1 Monthly Rainfall

Figure 2 shows the average monthly rainfall from January to December in current period (2001–2018), which was higher than baseline period (1981–2000). It was also mentioned in [18] of high increase of rainfall in Java in 2011–2016 compared to the previous year (1981–2010). After 2000, monthly rainfall tended to increase during the rainy season in October – March, with the peak of rainfall in January. In the dry season of 1981–2018, especially in August, the average rainfall in East Java was the lowest. However, the average monthly rainfall was higher than 150 mm, so that it remained sufficient to meet the needs of rice farming.

Based on the Mann-Whitney and Levene statistical tests, the monthly rainfall from January to December between the baseline (1981–2000) and current (2001–2018), both during dry and rainy seasons, are not statistically different. It can be seen in Table 1 that $p > 0.05$, which means that there is no significant difference in the monthly rainfall in the two compared periods (1981–2000 vs. 2001–2018). Our finding is conform with the study by [18], who found also similar and no significant difference between rainfall in 1981–2016 on Java Island.

4.1.2 Monthly Temperature

Figure 3 shows that the Average monthly temperature in the current period (2001–2018) is higher than the average temperature in the baseline period (1981–2000). An increase in average temperature by 0.3 °C, in case of an increase in global average temperature of 1 °C, may cause a decrease in rice production by 3.2 ± 3.7% [19]. The Mann-Whitney test in Table 2 shows that the average temperature in the rainy season in January ($U = 99.5$, $Z = -2.354$, $p < 0.05$) and February ($U = 90$, $Z = -2.631$, $p < 0.05$), as well as in the dry season in April ($U = 98$, $Z = -2.398$, $p < 0.05$), May ($U = 91$, $Z = 2.603$, $p < 0.05$) are statistically different. Similarly, for Levene test, temperature variability in January, February, April, May, and October are also significantly different between 1981–2000 and 2001–2018 periods.

In August to November, both in the baseline (1981–2000) and current period (2001–2018), there were increase in the average temperature every month in East Java Province. This confirms the results of the IPCC report that globally there has been an increase in temperature after the end of the nineteenth century by 0.85 °C [1]. The [20] research have confirmed that human emissions are the main cause of the global warming over the past 150 year.

Table 1. Monthly Rainfall Statistics Test

Average Rainfall	Mann-Whitney Test	Levene Test
January	U = 146, Z = .994, p > .05	F = .44, p > .05
February	U = 151, Z = −.848, p > .05	F = 2.806, p > .05
March	U = 143, Z = −1.082, p > .05	F = .008, p > .05
April	U = 169.5, Z = −.307, p > .05	F = .040, p > .05
May	U = 164, Z = −.468, p > .05	F = 1.612, p > .05
June	U = 146, Z = −.199, p > .05	F = 4.976, p > .05
July	U = 80, Z = −.534, p > .05	F = .083, p > .05
August	U = 18, Z = −.600, p > .05	F = .001, p > .05
September	U = 10.5, Z = −.419, p > .05	F = 3.744, p > .05
October	U = 60.5, Z = −.638, p > .05	F = 3.431, p > .05
November	U = 168, Z = −.091, p > .05	F = .207, p > .05
December	U = 175, Z = −.146, p > .05	F = 1.277, p > .05

4.1.3 Maximum Monthly Temperature

The maximum monthly temperature in the baseline (1981–2000) and current (2001–2018) periods shows no significant difference. The statistical test in Table 3 shows that the maximum temperature in January to December in the two periods (1981–2000 vs. 2001–2018) have no statistical difference, as indicated by the value of sig. $p > 0.05$. The average maximum temperature in 1981–2018 was around 32.3 °C. This shows that the maximum temperature is relatively lower than the limit of maximum temperature for rice plant's optimal growth at 35 °C [21]. Higher maximum temperature than that increases the risk of failure for the rice plant to flowering [22] (Fig. 4).

4.1.4 Minimum Monthly Temperature

Figure 5 shows that the minimum temperature in the current period (2001–2018) has increased compared to the baseline period (1981–2000). The increase of minimum temperature was about 0.68 °C. Changes in minimum temperature affect the growth of rice, where rice is very sensitive to changes in minimum temperature or cold stress compared to other cereals [23]. Changes in minimum temperature affect the strength of seedlings in the vegetative phase, reduce the number of tillers, and increase the risk of plant death [15].

The Mann-Whitney test in Table 4 shows that minimum temperature from September to May in the two periods (1981–2000 vs. 2001–2018) are statistically different (sig. $p < 0.05$). Meanwhile, Levene test that examines the minimum temperature variability shows that minimum temperature in January, February, March, April, May, October, November, and December are statistically different between the two periods. In other words, significant minimum temperature changes occurred during rainy season.

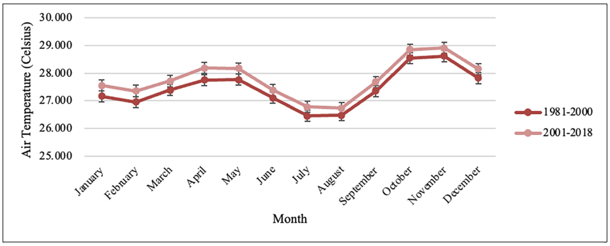

Fig. 3. Monthly Temperature in The Baseline (1981–2000) and Current Period (2001–2018).

Table 2. Monthly Temperature Statistics Test

Average Temperature	Mann-Whitney Test	Levene Test
January	U = 99.5, Z = −2.354, p < .05	F = .00, p < .05
February	U = 90, Z = −2.631, p < .05	F = .029, p < .05
March	U = 118, Z = −1.813, p > .05	F = .152, p > .05
April	U = 98, Z = −2.398, p < .05	F = 2.587, p < .05
May	U = 91, Z = −2.603, p < .05	F = 2.623, p < .05
June	U = 137, Z = −1.257, p > .05	F = 2.744, p > .05
July	U = 128, Z = −1.520, p > .05	F = .209, p > .05
August	U = 144, Z = −1.053, p > .05	F = .172, p > .05
September	U = 118.5, Z = −1.798, p > .05	F = 1.279, p > .05
October	U = 116, Z = −1.871, p > .05	F = 2.199, p < .05
November	U = 124.5, Z = −1.623, p > .05	F = .347, p > .05
December	U = 110.5, Z = −1.769, p > .05	F = .304, p > .05

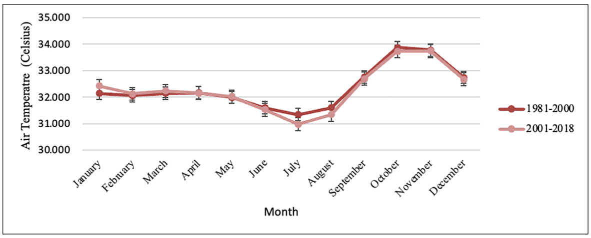

Fig. 4. Maximum Monthly Temperature in The Baseline (1981–2000) and Current Period (2001–2018).

4.2 Rice Production in East Java

Rice production in East Java Province shows an increasing trend every year from 1981–2018, as shown in Figs. 6, 7, 8, and 9. Some factors that affect the rice production include land area, climate, production input, and farm management [24]. In terms of land area,

Table 3. Maximum Monthly Temperature Statistics Test

Average Temperature	Mann-Whitney Test	Levene Test
January	U = 120, Z = −1.754, p > .05	F = .033, p > .05
February	U = 175, Z = −.146, p > .05	F = .050, p > .05
March	U = 153, Z = −.789, p > .05	F = 1.265, p > .05
April	U = 174.5, Z = −.161, p > .05	F = 245, p > .05
May	U = 159, Z = −.614, p > .05	F = .458, p > .05
June	U = 173, Z = −.205, p > .05	F = .092, p > .05
July	U = 155, Z = −.731, p > .05	F = 2.389, p > .05
August	U = 137.5, Z = −1.243, p > .05	F = .718, p > .05
September	U = 164.5, Z = −.453, p > .05	F = 5.460, p > .05
October	U = 148.5, Z = −.921, p > .05	F = 1.431, p > .05
November	U = 177, Z = −.088, p > .05	F = .544, p > .05
December	U = 168, Z = −.351, p > .05	F = .000, p > .05

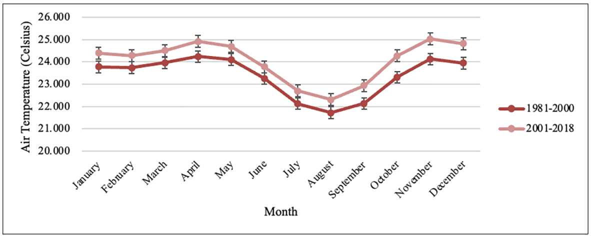

Fig. 5. Minimum Monthly Temperature in The Baseline (1981–2000) and Current Period (2001–2018).

East Java owns the largest rice field area in Indonesia [25], contributes up to 35% of rice production on Java Island, with average production of 9,325 tons per year.

Figure 6 shows a highly volatile rainfall in the course of last 38 years (1981–2018). Rainfall fluctuations in East Java cannot be separated from the influence of El Nino and La Nina events, weather anomalies in the equatorial Pacific Ocean that impact Indonesia periodically. In the period of 1981–2018, there were climate anomalies phenomenon with different intensities almost every year. El Nino occurred in 1982–1983 (very strong), 1987–1988 (strong), 1991–1992 (strong), 1997–1998 (very strong), 2009–2010 (moderate) and 2015–2015 (very strong). Meanwhile, La Nina happened in 1898–1999 (strong), 1999–2000 (strong), 2007–2008 (strong), and 2010–2011 (strong).

Decline in rice production due to decrease in rainfall can be seen in Fig. 6. El Nino reduced rainfall than normal, making irrigation water scarcer. Annual rainfall in 1995 was the lowest within the 38-year period between 1981 and 2018. Years of 1994–1995 experienced moderate El Nino event that caused decrease in rainfall. The impact of El

Table 4. Minimum Monthly Temperature Statistics Test

Average Temperature	Mann-Whitney Test	Levene Test
January	$U = 63, Z = -3.422, p < .05$	$F = .164, p > .05$
February	$U = 59.5, Z = -3.535, p < .05$	$F = .012, p > .05$
March	$U = 60, Z = -3.512, p < .05$	$F = .001, p > .05$
April	$U = 41, Z = -4.065, p < .05$	$F = .298, p > .05$
May	$U = 318.5, Z = -2.019, p < .05$	$F = .192, p > .05$
June	$U = 334, Z = -1.639, p > .05$	$F = .092, p > .05$
July	$U = 124.5, Z = -1.623, p > .05$	$F = 1.672, p > .05$
August	$U = 119.5, Z = -1.769, p > .05$	$F = .014, p > .05$
September	$U = 111, Z = -2.018, p < .05$	$F = 1.481, p > .05$
October	$U = 71.5, Z = -3.173, p < .05$	$F = .005, p > .05$
November	$U = 29.5, Z = -4.40, p < .05$	$F = 1.450, p > .05$
December	$U = 38, Z = -4.154, p < .05$	$F = .601, p > .05$

Nino, i.e., the dry period, was worst in 1997 and 2015 [5]. Strong El Nino in 1997 induced further decrease in rainfall and a long dry season. However, rice production in 1995–2000 were relatively stable despite lower rainfall. One reason, especially for 1997 El Nino, is that strong La Nina occurred right after that in 1998–2000. In fact, annual rainfall in 1998 were recorded as the highest in the 38-year period between 1981 and 2018, hence help compensating the lack of water during the El Nino period [26]. Similarly, La Nina happened in 2016 following the strong El Nino in 2015.

According to [27], the effect of El Nino on the decline in rice productivity was relatively small (−2.9%) compared to corn (−7.4%) and soybean (−10.7%). In comparison, research by [28] found that 2010 El Nino plummeted both rice and corn production, where the decline in corn production was greater than rice production. Rice requires 600–1200 mm of water for 90–120 days from planting to harvest. Unfulfilled water needs can interfere with the rice growth process, whether in the vegetative, flowering and grain filling phases [29]. Additionally, lack of water in the reproductive phase is riskier than in the vegetative, for the potential of decreasing production is higher. Reduced water availability leads to decreased photosynthesis leading to fewer resources available to plants for investment into reproduction and flowers. Drought reduces flower size and number, pollen, and pollen viability as well as the amount and quality of nectar that affect overall pollination [30]. Pollination is directly related to the fruit and seed yield. Grain yield decreases up to 14.63% under moderate and 40.37% under severe drought [31].

Figure 7 shows annual rice production and average temperature in East Java Province. The year 2016 was the year with the highest average temperature throughout the observation (1981–2018). The average temperature in 2016 was 28.6 °C, with the highest average temperature recorded in May, reaching 29.3 °C. Based on BMKG observations,

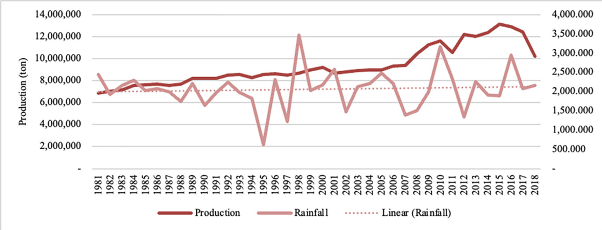

Fig. 6. Annual Rainfall and Rice Production (1981–2018).

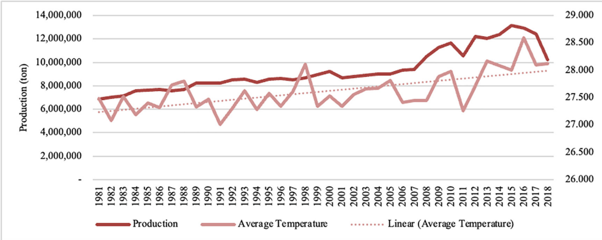

Fig. 7. Annual Average Temperature and Rice Production (1981–2018).

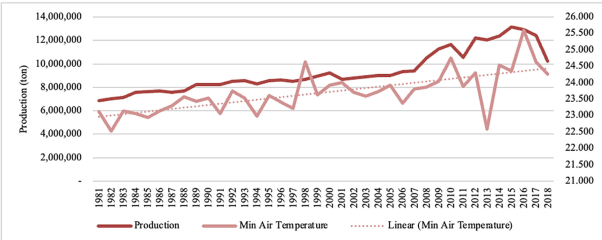

Fig. 8. Annual Minimum Temperature and Rice Production (1981–2018).

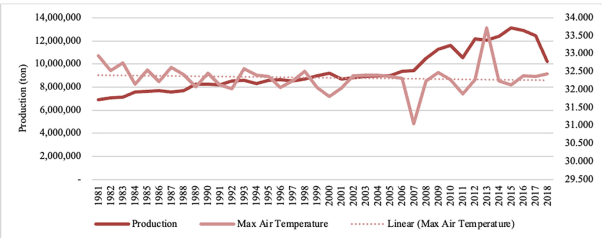

Fig. 9. Annual Maximum Temperature and Rice Production (1981–2018).

2016 was the year with the highest temperature compared to normal temperatures in 1981–2010.

In 1997, there was a very strong El Nino event that caused an increase in the average temperature, and 2011 experienced a moderate La Nina event that led to a decrease in the average temperature to 27 °C. Changes in the average temperature from 1981–2018 showed a positive trend. According to the research by [8] showed that an increase in the average temperature had no significant effect on rice productivity. In this study, it is explained that in tropical climates it is more sensitive to changes in minimum and maximum temperatures that affect rice productivity than changes in average temperature. However, according to [19, 32] mean temperature has the negative effect on rice production. We see that high and low average temperature did not always lead to decreasing rice production, such as those in 1998 and 2010.

An interesting relationship is seen in 2011, when low annual average temperature (i.e., 27 °C) is associated with lower production. This may be explained by the presence of La Nina since 2010 that last in the overall 2011. In other words, we found that La Nina does not always lead to increase in rice production.

Figure 8 shows fluctuations in minimum temperature from 1981 to 2018. The anomaly of temperature changes in 1998 and 2016 led to an increased minimum temperature, which happened throughout Indonesia. A change in temperature anomaly in 1981–2018 was 0.8 °C and occurred in 2016. The minimum temperature change in 1981–2018 has a positive trend and faster than the maximum temperature change in Fig. 9. This shows that climate change has more influence on the minimum temperature increase [21]. The increase in minimum temperature influences fluctuations in rice production which can be seen in (Fig. 8). The increase in minimum temperature has a positive effect on rice plants at the replanting stage. The increase in minimum temperature causes an increase in the rate of leaf growth, an increase in the number of tillers and stem elongation which results in an increase in rice production during the vegetative phase. However, increase of minimum temperature above 25 °C has a negative impact on rice plants. This can be seen in 1981–2015, where an increase in the minimum temperature was coherent with an increase in rice production. However, after 2016, or when highest temperature was recorded, rice production decreased. An increase in the minimum temperature has a negative impact on the stage of growth and flowering during the reproductive phase. Our results are the same as [8], where rice fluctuations occur when there is a minimum temperature increase.

Figure 9 shows fluctuations in the maximum temperature in East Java Province from 1981 to 2018. The maximum temperature increases from 1981–2018 is still relatively lower than the limit for rice plants to grow optimally, which is 35 °C. Research by [32] stated that the maximum temperature increases above 35 °C may decrease productivity by affecting the ripening period.

Looking at the rice production trend relative to fluctuation in maximum temperature (Fig. 9), a change in the maximum temperature increase will increase rice production at the optimum point or have a U-shape tendency [8]. This point is the peak of the optimal temperature of the maximum temperature change that can increase rice production. A study by [32] in Pakistan found that the optimal temperature for rice to increase production was 35 °C. After reaching the optimal temperature, the maximum temperature change has a negative impact on rice plants at the replantation stage during the vegetative phase. The increase in maximum temperature at the replantation stage increases the rate of photosynthesis and shortens the life cycle of rice plants, resulting in a decrease in rice production. This is shown in Fig. 9 that the maximum temperature changes along with the increase in production reached the optimal point in 2013 and decreased thereafter. According to [33], who conducted a study in India, maximum temperature increase of 1 °C can rise crop yields by 24 kg/ha. However, after reaching the optimum point, increase in maximum temperature will lower rice production. Research by [8] that observed rice production center Indonesia showed that maximum temperature increase is optimal at 31.35 °C.

5 Conclusion

Overall, we conclude that annual rainfall in the baseline period (1981–2000) was 2,044 ± 603 mm/year and the current period (2001–2018) was 2,117 ± 117 mm/year. High rainfall typically occurs December, January, and February, while June to October experienced relatively low rainfall. The average monthly air temperature in East Java Province ranged from 23.7–32.3 °C, with an average temperature of 27.6 °C per month. The statistical test indicated that average, minimum and maximum monthly temperatures in current (2001–2018) was higher that baseline (1981–2000) period. Statistically significant changes were shown in the average and minimum temperatures. The occurrence of fluctuation in changes in rainfall, average, minimum and maximum temperatures indirectly affected changes in rice production in 1981–2019 in East Java Province.

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