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RISK OF RICE YIELDS CAUSED BY TEMPERATURE AND RAINFALL CHANGE IN KARAWANG WEST JAVA

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ABSTRACT

Karawang Regency is experiencing climate change as seen by changes in temperature and rainfall, which impacts the agricultural sector, especially a decrease in rice yields. Change of rice yields due to variations in temperature and raifall can be studied using hazard, vulnerability and risk analysis. This research identified the magnitude of temperature and rainfall variations and analyze the potential for hazard, vulnerability, and risk of reduced rice yields in Karawang Regency. This research uses descriptive and quantitative methods. The data used are rainfall, temperature, rice planting and harvest area, rice production, and socioeconomic data of farmers from BPS, BMKG, and the Karawang Regency Agriculture and Food Security Office, and other sources. This study found the fact that Karawang Regency experienced a decrease in average rainfall of 109.97 mm and an increase in average air temperature of 0.9^{0}C in the period 1991 - 2022. The sub-districts that have a very high risk of rice production decline with risks index >0.81 are Tempuran and Tirtajaya sub-districts; high risk of rice production decline with risks index 0.61 - 0.80 is Cilamaya Wetan sub-district. Most other sub-districts in Karawang Regency have a risk of decreasing rice yields at varying levels, from very low to moderate.

1. INTRODUCTION

Rice is the staple food crop for the people of Indonesia. Nearly 95% of Indonesia's population consumes rice, which is a major reason it is the primary food crop widely cultivated each year (Pratiwi, 2016). The demand for rice continues to rise due to Indonesia's growing population; therefore, efforts are needed to consistently increase rice production each year. However, in these efforts to increase rice production, many challenges arise, including threats from climate change, driven by shifts in rainfall patterns and air temperature. Rice crops are significantly affected by climate change due to shifts in rainfall patterns and the rainy season, which are extremely difficult to predict (Zaini & Saitama, 2023; Ramadhan, 2024; Rozci, 2024).

Changes in rainfall are closely linked to the ENSO (El Niño and La Niña) phenomena. Rainfall in Indonesia has decreased due to the El Niño phenomenon. This decrease in rainfall often leads to drought, resulting in low crop productivity, delayed planting, reduced planted area and harvest yields, disrupted rice plant growth due to water scarcity, and even crop failure or fuso (Akram *et al*., 2013; Ichsan *et al*., 2021). Rice plants are highly dependent on climatic factors, namely rainfall and air temperature (Pramasani & Soelistyono, 2018). This dependence is evident in the physiological effects on rice when rainfall decreases and air temperature rises, namely: inhibition of grain filling and maturation, a decrease in the rate of photosynthesis that affects carbohydrate formation, and reduced pollen viability, all of which lead to yield loss (Cahyaningtyas *et al*., 2019).

Excessively high air temperatures can reduce water availability in plants and soil. Air temperature affects photosynthesis, respiration, transpiration, growth, fertilization, and pollination. According to Efendi *et al*. (2014) a 5 °C increase in air temperature reduces crop production by 40%. In their study, Herlina & Prasetyorini (2020) stated that air temperature can affect productivity by 32%. A rise in air temperature can reduce rice productivity because nighttime respiration increases and the risk of disease and pest attacks on plants rises. The increase in temperature also affects respiration rates and shortens the plant's lifespan, thereby reducing crop production. According to the results of a study by Hosang *et al*. (2012) involving simulations, a temperature increase of 1°C, 1.5°C, and 2°C, accompanied by rainfall increases of 5%, 10%, and 15%, respectively, showed a decrease in productivity corresponding to each temperature rise and rainfall percentage, specifically 6.3 metric tons/ha; 5.29 metric tons/hectare; and 4.55 metric tons/hectare, respectively. Other studies have shown that a 1% increase in air temperature compared to current levels can reduce rice yields by 3.44% (Tang, 2019).

El Niño events, characterized by decreased rainfall and rising air temperatures, and La Niña events, characterized by above-normal rainfall, are both climatic anomalies that are detrimental to food crop production. This is because the drastic decrease in rainfall associated with El Niño can cause crop failures due to drought and reduced productivity, while the increased rainfall associated with La Niña can lead to flooding and increased plant pest infestations. Since food crops have a relatively short growth cycle, these two climate anomalies can have a greater impact on food crop production (Irawan, 2006; Salman & Ayufitria, 2016; Putranto, 2021; Chaniago, 2023).

Analysis to determine the impact of changes in air temperature and rainfall on crop production can utilize three components: hazard, vulnerability, and risk (Ruminta, 2016; Weis *et al*., 2016; Hastanti & Purwanto, 2020; Intergovernmental Panel on Climate Change (IPCC), 2021). A hazard is the potential for a decline in crop production resulting directly or indirectly from increases in air temperature and changes in rainfall patterns, which are linked to plant photosynthesis and respiration, as well as disruptions to crop growth and yield, crop failure, reductions in planted area and harvest volume, changes in cropping patterns, and other related effects. Vulnerability is the degree to which farmers, farmer groups, or agricultural practitioners are able to adapt to, anticipate, cope with, sustain crop cultivation activities, and protect themselves from the impacts and hazards of climate change events. Risk is the likelihood of losses in crop yields resulting from changes in rainfall and air temperature in a given region at a specific time, such as declines in crop productivity and production, which lead to a reduction in income for farmers or crop growers. According to Metternicht *et al*. (2014) and Ruminta *et al*. (2018), these three analyses were conducted to determine the impacts of changes in rainfall and air temperature on agriculture and to identify strategic predictions and adaptation measures.

In 2021, West Java ranked third among Indonesia's 10 largest rice-producing regions, with paddy production of 9.35 million metric tons (Badan Pusat Statistik (BPS), 2024). Karawang Regency is the second-largest rice-producing region in West Java after Indramayu Regency and is known as the "National Rice Granary" (Chofyan *et al*., 2016). Although Karawang Regency has high rice production and productivity, it has not yet met its targets due to several issues, including climate change, such as El Niño, La Niña, rising air temperatures, changes in rainfall patterns, and extreme weather events like droughts and floods. In 2023, Karawang Regency experienced a drought that affected more than 1,000 hectares due to a prolonged dry season, particularly in the subdistricts of Banyusari and Pakisjaya (Khumaini, 2023). This has caused rice production in Karawang Regency to decline between 2021 and 2023, from 1,234,134 metric tons to 1,096,657 metric tons (BPS Provinsi Jawa Barat, 2024). Therefore, to maintain or increase rice production in Karawang Regency, input from various parties is needed, including findings from studies on the effects of changes in air temperature and rainfall.

This study assesses the magnitude of climate change using indicators of changes in air temperature and rainfall, and analyzes the levels of hazard, vulnerability, and risk to rice production in Karawang Regency. The results of identifying the magnitude of changes in air temperature and rainfall, as well as the analysis of the levels of hazard, vulnerability, and risk of reduced rice production caused by these changes, are highly beneficial for farmers, agricultural extension workers, and the local government of Karawang Regency in formulating strategic anticipatory and adaptive measures to address climate change. Furthermore, the results of this study are important as input for formulating policies and planning the development of rice cultivation in Karawang Regency, both in the medium and long term.

2. MATERIALS AND METHOD

The study location was Karawang Regency, West Java, situated between 107°02' – 107°40' East Longitude and 5°56' – 6°34' South Latitude in 2024. The research data consisted of air temperature and rainfall data from 1991 to 2022 obtained from the Citeko Station of the Meteorology, Climatology, and Geophysics Agency (BMKG), as well as rice crop data, including land area, harvested area, production, elevation, and socioeconomic data (number of farmers, farmers' education level, and farmers' income), obtained from the Karawang Regency Food Crops and Forestry Service and the Karawang Regency Central Statistics Agency (BPS) (BPS Karawang Regency, 2024). Additional data included monthly average rainfall and air temperature for each subdistrict in Karawang Regency, obtained from the Karawang Regency BPS.

This study employed descriptive and quantitative methods to analyze changes in temperature and rainfall and their effects on rice production in Karawang Regency. The research data were analyzed using Microsoft Excel 2019 and Minitab 19 statistical software to determine the magnitude of climate change, hazard indices, vulnerability indices, and rice production risks. The analysis results were interpreted or presented spatially using ArcGIS software.

The analysis steps conducted were as follows: determining the magnitude of shifts in temperature and rainfall using annual rainfall data from 1991 to 2022; analysis of changes in climatograms using monthly precipitation and temperature data; and analysis of hazard, vulnerability, and risk using temperature and precipitation data, rice crop data, and socioeconomic data for each subdistrict to calculate the levels of hazard, vulnerability, and risk to rice production resulting from changes in air temperature and precipitation in Karawang Regency. The risk analysis model for changes in air temperature and rainfall is defined as the risk of hazardous losses or reductions in rice production resulting from changes in these climate change indicators (Saefudin et al., 2021).

2.1 Climate Change Analysis

Calculating the extent of climate change using indicators such as precipitation and air temperature, as well as climograms, over a 31-year period from 1991 to 2022.

2.2 Hazard Analysis

A hazard analysis was conducted to determine the hazard index, specifically, the decline in rice production resulting from changes in air temperature and rainfall, which is the cumulative effect of reduced productivity, decreased harvested area, reduced cultivated land area, and crop failure (Ruminta, 2016; Ruminta *et al*, 2017; Akmalia, 2022; Jamil & Chairunnisya, 2023).

2.2.1 Decrease in Rice Yield Due to Rising Air Temperature

The relationship between rising air temperature and increased plant respiration, which leads to a decrease in rice yield, can be expressed using the Temperature Quotient equation, where the respiration rate increases by two raised to the power of the difference between the air temperature and the baseline temperature for every 10°C rise in air temperature.

$$Q_{10} = 2^{(T-20)}/10 \qquad (1)$$

The change in rice yield due to rising air temperature, as indicated by increased respiration, can be expressed using the following formula:

$$\Delta Yp_1 = Y_0(Q_{10} - Q_{10o}) \qquad (2)$$

Notes: T = air temperature (°C); $\Delta Yp1$ = potential yield reduction due to increased rice plant respiration (metric tons/ha); Y0 = rice yield before the air temperature increase (metric tons/ha); Q_{10} = Temperature Quotient at the air temperature after the increase; Q_{10o} = Temperature Quotient at the air temperature before the increase.

Higher air temperatures result in a shorter plant lifespan, lower plant biomass, and ultimately reduced rice yields. Handoko *et al*. (2008) and Takama *et al*. (2015) state that the relationship between yield reduction caused by plant lifespan due to increased air temperature can be expressed by the following equation:

$$Yp_2 = Y_0(T_0 - T_b)/(T - T_b) \qquad (3)$$

$$\Delta Yp_2 = Y_0 - Yp_2 \qquad (4)$$

Notes: ΔYp_2 = potential decrease in rice yield due to reduced plant age (metric tons/hectare); Y_0 = rice yield before the increase in air temperature (°C); T_0 = air temperature before the increase (°C); T = air temperature after the increase (°C); T_b = baseline temperature for rice plants (°C).

2.2.2 Changes in Rice Yield Due to Changes in Rainfall

Calculations of changes in rice yield are based on the assumption that rainfall is the sole water source throughout the rice growing season; the relationship between rice yield and rainfall can be expressed by the following equation:

$$Y = K \times P \qquad (5)$$

Notes: Y = rice crop yield (metric tons/ha); k = constant for rice crops (metric tons/(ha.mm)); P = rainfall (mm).

Based on Equation (5), changes in rainfall that have the potential to cause droughts and floods can result in a decrease in rice yield, expressed as follows:

$$\Delta Yp_3 = k \times \Delta P \quad (6)$$

Notes: ΔYp_3 = potential decrease in rice yield (metric tons/ha) due to drought; k = constant for rice crops (metric tons/(ha·mm)); ΔP = change in rainfall (mm).

Thus, the combined effect of shifts in temperature and rainfall on the decline in rice yield can be expressed by the following equation:

$$\Delta Y_a = \max(\Delta Yp_1, \Delta Yp_2, \Delta Yp_3) \quad (7)$$

Notes: Y_a = decrease in rice yield due to increased air temperature (metric tons/ha); ΔYp_1 = potential decrease in rice yield due to increased rice plant respiration (metric tons/ha); ΔYp_2 = potential decrease in rice plant lifespan (metric tons/ha); ΔYp_3 = potential decrease in rice yield due to drought (metric tons/ha).

2.2.3 Vulnerability Analysis

Ruminta *et al*. (2018) stated in their study that the vulnerability of rice cultivation related to climate change (changes in air temperature and precipitation) can be assessed using three components: exposure (E), sensitivity (S), and adaptive capacity (AC).

$$V = \frac{E \times S}{AC} \quad (8)$$

Notes: V = Vulnerability; E = Exposure; S = Sensitivity; AC = Adaptive Capacity.

The exposure indicator (E) refers to the components of rice cultivation affected by changes in air temperature and rainfall, namely the area of rice fields and the number of farmers. Sensitivity indicators (S) are factors related to rice cultivation that are responsive to changes in air temperature and rainfall, such as the type of rice-growing land and elevation (m above sea level). Adaptive capacity indicators (AC) are represented by farmers' education levels and income.

2.2.4 Risk Analysis

The risk analysis of a decline rice yields due to changes in air temperature and rainfall is a potential source of negative impacts or losses, represented as a threat of reduced yields (Ruminta *et al*. 2017). The potential risk associated with changes in air temperature and rainfall can be calculated using the following formula:

$$R = H \times V \quad (9)$$

Notes: R=Risk; H = Hazard.

3. RESULT AND DISCUSSION

3.1. Changes in Air Temperature, Rainfall, and Climogram in Karawang Regency

Karawang Regency has an average temperature of 27°C, relative humidity of 80%, and sunshine duration of 66%. Rainfall ranges from 1 to 304 mm, with an average of 6 rainy days per month; the highest rainfall occurs in January, while the lowest is in September (BPS Provinsi Jawa Barat, 2024). From January through April, the Sea Monsoon prevails, and in June, the Southeast Monsoon occurs, with wind speeds of 30-35 km/h and wind durations of 5-7 hours (BPS Provinsi Jawa Barat, 2024). This study indicates that the climate in Karawang Regency during 1991–2022 changed, as shown in Table 1.

Table 1 shows that Karawang Regency experienced a decrease in rainfall of 109.87 mm. This change is related to the ongoing El Niño climate phenomenon. The El Niño climate anomaly weakens the easterly trade winds, causing them to shift direction toward the east and pushing rainfall potential toward the eastern regions, thereby altering weather patterns across Indonesia. These results are consistent with research by Ruminta *et al*. (2018) in the South Sumatra and Greater Malang regions, which experienced rainfall decreases of 197 mm and 550 mm, respectively, due to climate change. In addition to the decrease in rainfall, Karawang Regency also experienced an increase in air temperature of 0.91°C from 1991 to 2022. These climate changes indicate that Karawang Regency is experiencing El Niño; alongside the decrease in rainfall, which is consistent with the rise in temperature, this has led to drought conditions. This is consistent with the findings of Papakostas *et al*. (2010), who noted that global surface temperatures during the 1880–2012 period increased by 0.65-1.06°C. Regions across Indonesia generally experienced rising air temperatures; for example, the Semarang region saw a temperature rise of 0.03°C per year, exceeding the national average of 0.02°C per year (Suryadi *et al*., 2017).

A climogram is a graph illustrating the interaction between two climatic elements, precipitation and temperature, in a given region, as they relate to the plant growth index. Two climograms for Karawang Regency were generated using monthly average precipitation and temperature data for Period I (1991–2006) and Period II (2007–2022), respectively, as shown in Figure 1. Figure 1 shows that Karawang Regency has experienced a change in its climogram, shifting from the lower region (Period I) to the upper region (Period II). This indicates a significant increase in air temperature and a shift in the timing of the highest air temperature, from May (24.79 °C) to September (25.48 °C). In addition, rainfall patterns have also changed: the periods of high rainfall, which originally occurred in January, February, and March (330.31 mm, 331.19 mm, and 213.33 mm, respectively), have shifted to January and February, with amounts of 274.08 mm and 323.68 mm, respectively. These changes in the climatogram will impact the growth and yield of rice crops.

Table 1. Changes in Rainfall and Air Temperature in Karawang Regency

Climate Indicator	Changes in Rainfall and Air Temperature		Magnitude of Change
	Periode 1991 - 2006	Periode 2007 - 2022	
Average rainfall (mm)	1,878.56	1,768.69	-109.87
Average air temperature (°C)	24.14	25.05	+0.91

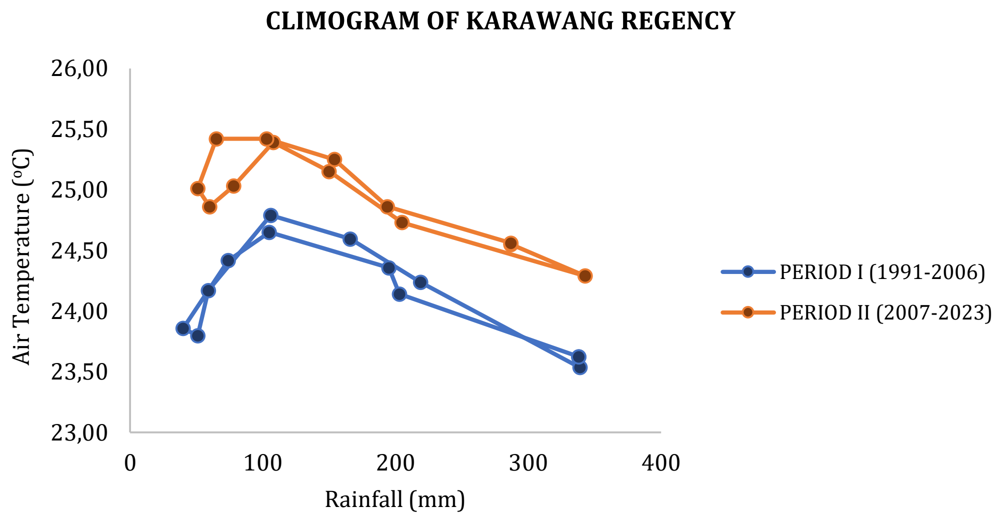

Figure 1. Climogram of Karawang Regency

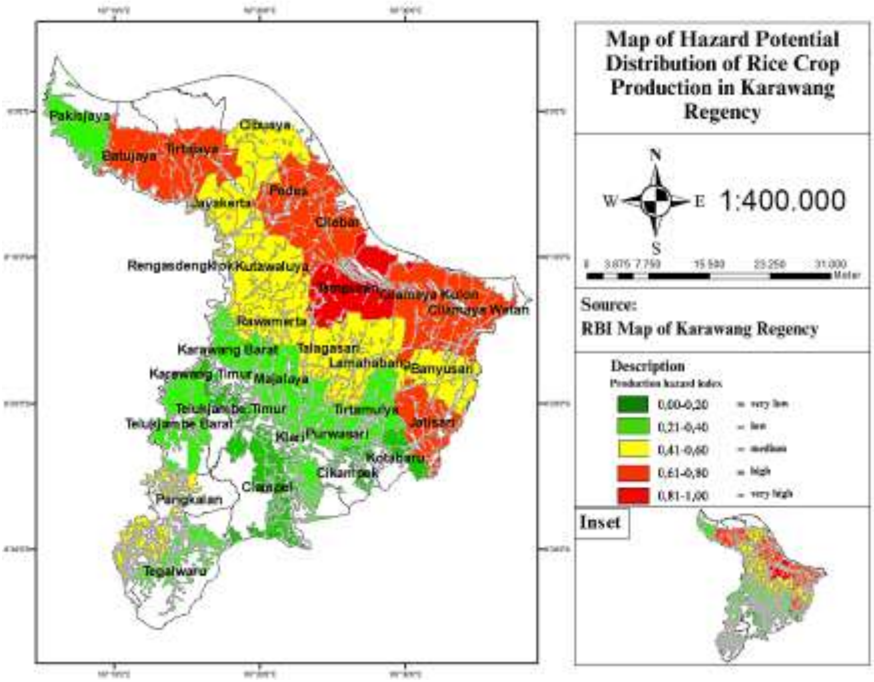

Figure 2. Map showing the distribution of potential hazards related to a decline in rice production in Karawang Regency.

3.2. Potential Risks of Declining Rice Production in Karawang Regency

The results of the hazard analysis of the decline in rice production in Karawang Regency, using rainfall and air temperature data, as well as rice production data for each subdistrict collected from 1991 to 2022, are shown in Figure 2. This figure is a spatial map of the hazard index for rice production decline due to changes in rainfall and air temperature (climate change). Based on the figure, the potential risk of rice production decline in Karawang Regency is predominantly at the low and very low levels, affecting 13 subdistricts. The average potential risk of a decline in rice production across subdistricts in Karawang Regency is 15%. The results of the analysis of the potential for a decline in rice production show that Karawang Regency also has a very high potential for decline, such as in Tempuran Subdistrict, amounting to 7,525 metric tons, and a high potential for decline in 7 subdistricts, namely Jatisari, Cilamaya Wetan, Cilamaya Kulon, Pedes, Cilebar, Tirtajaya, and Batujaya, with potential rice production declines of 5,166.48 metric tons; 4,766.59 metric tons; 4,754.35 metric tons; 5,851.37 metric tons; 5,636.57 metric tons; 5,091.62 metric tons; and 4,822.30 metric tons.

This potential decline in rice production is due to shifts in rainfall and air temperature, which are closely linked to rice plant growth and yield. In Karawang Regency, air temperatures have increased while rainfall has decreased. Air temperature plays a crucial role in rice plant growth because every stage of rice growth depends on it. Air temperatures that are not optimal for rice growth can reduce tillering rates, delay leaf development, and even inhibit leaf elongation in rice plants (Hussain *et al*. 2019). Furthermore, changes in air temperature also cause leaves to turn yellow during the growing season, which slows rice plant growth and results in immature or suboptimal development (Ghazouani & Teraoui, 2017). The negative effects of rising air temperatures on rice plants cause abiotic stress, leading to a decrease in the weight of filled grains per plant and, consequently, reduced production and suboptimal yields (Jaisyurahman *et al*., 2019). Furthermore, the decrease in rainfall occurring in Karawang Regency can lead to drought in the area. As a result of these rainfall changes, water stress may occur in rice plants, adversely affecting their metabolism and potentially leading to reduced yields or crop failure (Abbas & Mayo, 2021).

Rice plants require adequate rainfall to avoid crop failure, and this must be adapted to both climatic and soil conditions. Changes in air temperature and rainfall also cause crop failure (puso) (Ishaq *et al*., 2017). Another impact is the outbreak of plant pests and diseases, which can also reduce rice production; for example, an outbreak of the rice stem borer *(Scirpophaga innotata)* can cause yield losses of 10–30% (Damayanti *et al*., 2015).

3.3. Vulnerability in Karawang Regency

The results of the vulnerability analysis for rice production in Karawang Regency, using a combination of three vulnerability components, exposure, sensitivity, and adaptive capacity, are presented in Figure 3. The results of this vulnerability analysis indicate that high levels of exposure and sensitivity can increase vulnerability, whereas higher farmers' adaptive capacity in a subdistrict reduces vulnerability; thus, it can be concluded that farmers' adaptive capacity in a subdistrict is inversely proportional to vulnerability. Results of the vulnerability analysis in Karawang Regency.

Based on the vulnerability analysis results, a very high vulnerability index was found only in Tirtajaya Subdistrict, at 1.00. Subdistricts with a high vulnerability index were limited to two: Cilamaya Wetan and Tempuran, with indices of 0.77 and 0.80, respectively. Most other subdistricts in Karawang Regency have vulnerability indices ranging from very low to moderate. Tirtajaya Subdistrict has a very high vulnerability index due to a very high exposure index of 0.96, a very high sensitivity index of 0.87, and a low adaptive capacity index of 0.40. The vulnerability analysis results indicate that Tirtajaya Subdistrict is highly vulnerable to climate change in Karawang Regency.

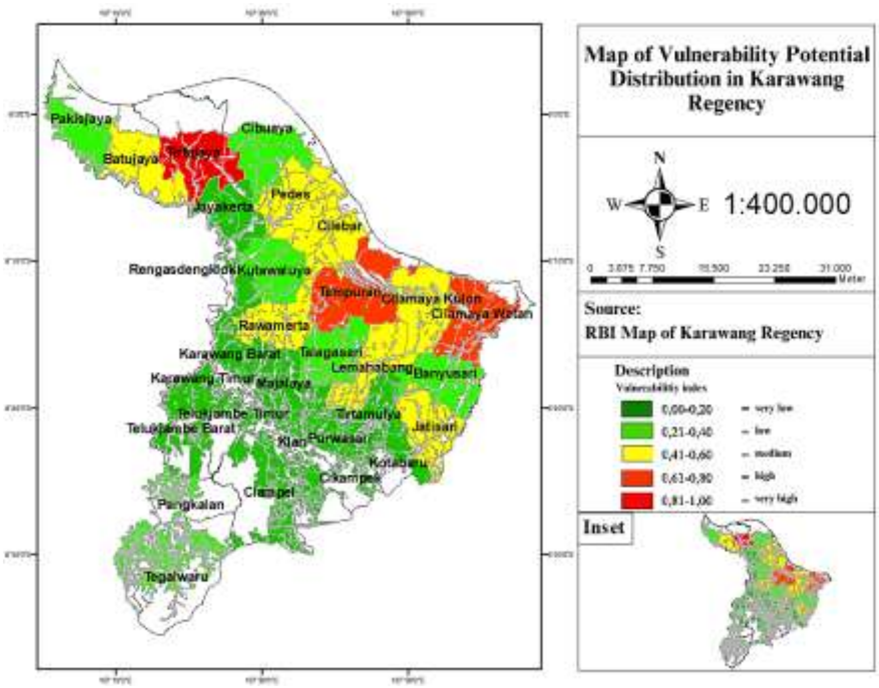

Figure 3. Map of Potential Vulnerabilities in Karawang Regency.

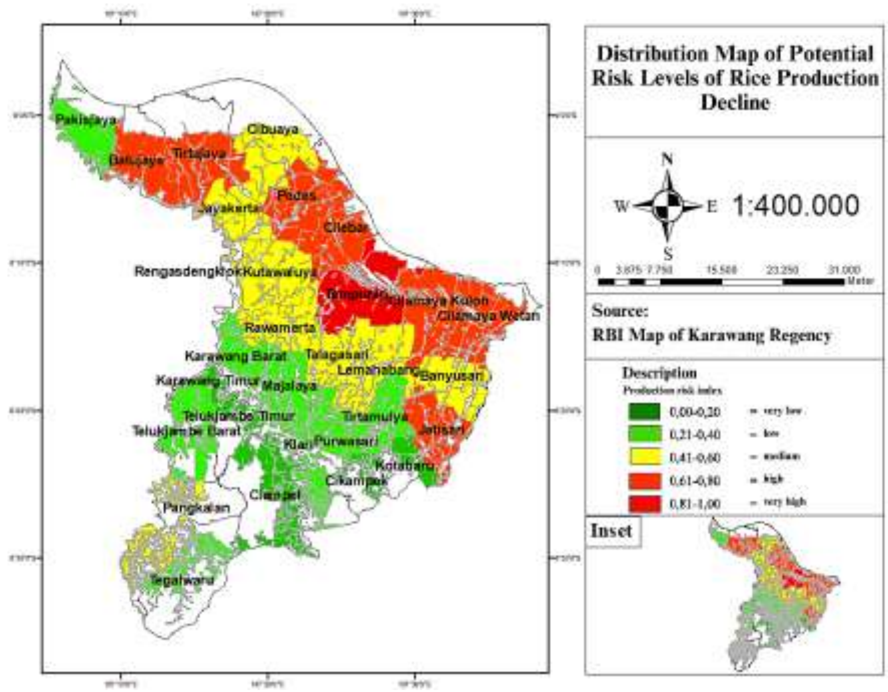

Figure 4. Map showing the distribution of potential risk levels for rice production declines in Karawang Regency.

3.4. Risks of Changes in Rice Production

The risk analysis of changes in rice yields in Karawang Regency due to climate change was based on two parameters: the hazard analysis and the vulnerability analysis. A risk analysis was conducted on rice production to assess the potential risk of a decline in rice production in each subdistrict of Karawang Regency, and the results are shown in Figure 4. It is evident that two subdistricts, Tempuran and Tirtajaya, have a very high risk of rice production decline, with risk indices of 1.00 and 0.88, respectively. This is because both subdistricts have high and very high levels of hazard and vulnerability. Tempuran Subdistrict has a very high hazard level of 1.00 and a high vulnerability level of 0.77. Meanwhile, Tirtajaya Subdistrict has a high hazard level of 0.68 and a very high vulnerability level of 1.00. The only subdistrict at high risk of production decline is Cilamaya Wetan, with an index of 0.66. Most other subdistricts in Karawang Regency have a risk of rice production decline ranging from very low to moderate. In areas at high risk of rice production decline, strategic adaptation efforts are needed to mitigate this threat and maintain or even increase rice production (Zhao *et al.*, 2014; Priyanto *et al.*, 2021).

4. CONCLUSIONS

This study draws several conclusions: Karawang Regency experienced a decrease in rainfall of 109.97 mm and an increase in air temperature of 0.9°C between 1991 and 2022; the climogram for the region also shifted from the lower range (Period I climogram) to the upper range (Period II climogram), indicating a decrease in rainfall and an increase in air temperature. The decrease in rainfall and the increase in air temperature have the potential to reduce rice production and productivity by 15% each. The potential risk of a decline in rice production is very high in Tempuran Subdistrict and high in Jatisari, Cilamaya Wetan, Cilamaya Kulon, Pedes, Cilebar, Tirtajaya, and Batujaya Subdistricts. Vulnerability is very high in Tirtajaya Subdistrict and high in Cilamaya Wetan and Tempuran Subdistricts. The risk of a decline in rice production is very high (risk index >0.80) in Tempuran and Tirtajaya Subdistricts, and high (risk index 0.61–0.80) in Cilamaya Wetan Subdistrict.

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