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Rainfall and Temperature Change Analysis and their Effect on Maize Production in Karawang, West Java

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ABSTRACT

Maize is an important food commodity and its yields is threatened by changes in climate variables, such as increasing air temperature and decreasing rainfall. The research identifies and detects the change in climate variables and analyze their correlation with maize production. Quantitative and descriptive methods were used namely trend analysis, correlation, and regression. We utilized climate data (temperature and rainfall) and maize production for 1991-2022, with tested study area in Karawang, West Java. We divided the climate data into two periods to analyze any change in climate variables. The results indicated a change in temperature (+0.56 °C) and rainfall (-47.34 mm) per year, but there is no change in the agroclimatic zone. Our findings showed a moderate correlation between rainfall and maize production and productivity, with the mean correlation coefficients of 0.31 and 0.35, respectively. Similarly, air temperature showed a moderate correlation with maize production and productivity, with the mean correlation coefficients of 0.30 and 0.32, respectively. Appropriate anticipatory and adaptation efforts are needed to maintain maize production in rainfed agriculture such as in Karawang Regency.

KEYWORDS
climograph shift, correlation, dryland, productivity, rainfall variability, trend

1. INTRODUCTION

Maize (*Zea mays* L.) has a significant role in food diversification to support national food security and serves as a versatile food commodity with various applications, including fuel and industrial raw materials (Dabija et al., 2021; Mango et al., 2018). This contribution has escalated the demand for maize with increased population. However, maize production in Indonesia has not met the growing consumer demand yet as maize import is still on the rise to fulfill domestic needs (BPS, 2023). Therefore, efforts to increase maize production continue despite the threat of climate change (Zai et al., 2024).

Maize growth is influenced by internal (genetic) and external factors. Climate is one of the most influential external factors, especially rainfall and air temperature (Idumah et al., 2016). Rainfall plays an important role in maize production by regulating water availability and changing the pattern of the onset of rainy and dry seasons (Du and Xiong, 2024; Krell et al., 2021). Excessive rainfall can increase soil water volume leading to water logged that inhibits plant growth, which reduces maize productivity (Manghwar et al., 2024). Maize is typically a C4 plant type, which has a good tolerance to drought, but drought stress due to prolonged low rainfall can potentially reduce its productivity (Azrai et al., 2024). Water shortage can inhibit the seed-filling phase and cause plants to wilt, while excess water may destabilize plants, hinder growth, and increase their disease susceptibility (Mapfumo et al., 2020).

Temperature influences plant activities, such as transpiration, photosynthesis, growth, and pollination.

High temperature inhibits the growth of maize during the critical phase of flowering and seed-filling by reducing water availability both in soil and plant body. An increased air temperature by 2°C can reduce maize production by 40% (Fatima et al., 2020). Meanwhile, low temperature may cause plant damage (chilling or freezing injury) (Li et al., 2021).

West Java is one of the maize production regions in Indonesia, with an average production of 1 million tones for 2010-2017 (BPS, 2023). Karawang Regency is one of largest contributors for maize production in West Java Province. Maize crops in Karawang are generally cultivated on dryland with combination of maize-maize or maize-other cropping patterns. A small portion is also cultivated in non-technically irrigated rice fields as an intercrop after rice cultivation (Mulya and Hudalah, 2024). Any change in global climate system will disrupt maize production including in local scale of Karawang.

This study examines the changes in rainfall and air temperature variables and their impact on maize production in Karawang Regency for 1991 - 2022. The results provide an important information to deal with climate change, especially for preventive solutions to minimize maize production losses for farmers, agricultural extension workers, the community, and the government in formulating medium and long-term agricultural development policies and planning.

2. RESEARCH METHODS

2.1 Research Location

The study site was in Karawang Regency, West Java, which is geographically located between 107º02'–107º40' East and 5º56'–6º34' South (Figure1). The northern part of Karawang Regency is mostly lowland, with altitude ranging from 3 – 25 m a.s.l and slopes between 0 – 2%. In contrast, the southern part features a small undulating and hilly terrain area, with altitude ranging from 26 – 250 m a.s.l and slopes between 15-40%. Soil types are generally ultisols with soil pH between 5-6. The area of agricultural land in Karawang Regency is approximately 98,164 ha, consisting of 64,311 ha of paddy fields and 33,853 ha of gardens or moorlands (BPS, 2023).

2.2 Data

Annual rainfall and air temperature data from the BMKG Citeko Station, along with annual maize productivity and production data from the Agriculture Agency and the Central Bureau Statistics of Karawang Regency (1991–2022), were analyzed to identify trends and calculate temporal coefficients correlation between rainfall, air temperature, maize productivity, and maize production.

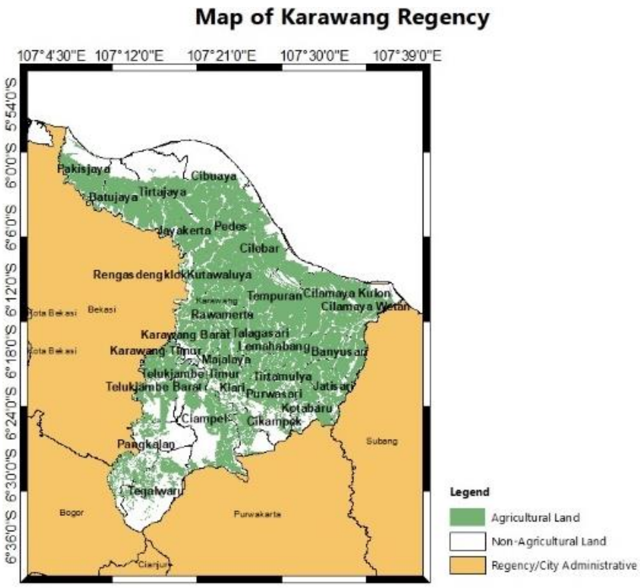


Figure 1. The land-cover distribution with agriculture (green) domination throughout Karawang Regency, West Java.

Additionally, sub-district-level data on annual rainfall, air temperature, productivity, and maize production (2001–2014) were utilized to calculate spatial correlation coefficients, examining the relationship between climatic variables and maize productivity or production across different sub-districts. Monthly average rainfall and air temperature data were also used to construct climographs.

2.3 Method

This research used a quantitative descriptive method to identify the magnitude and trend of changes in rainfall, air temperature, and climograph and their correlation with maize production and productivity. Data processing and analysis were performed using Minitab 18 software, and the analysis results were interpreted as spatial maps using GIS application.

The analysis stages included determining the magnitude of changes in rainfall and air temperature. Then we performed a trend analysis of these changes based on a linear regression model (Equation 1), where the constant value and slope of the trend line were derived.

$$Y = b_0 + b_1 X \; ; \qquad (1)$$

$$b_0 = \frac{(\sum_{i=1}^{n} Y_i)}{n} \text{ and } b_1 = \frac{\sum_{i=1}^{n} (X_i Y_i)}{\sum_{n=1}^{n} (Y_i)^2}$$

where: Y = a trend value of rainfall or air temperature; b_0 = constant value i.e. the value of Y when the value of X = 0; b_1 = value of the trend line slope, X = the year-period value.

Changes in the climograph were analyzed to

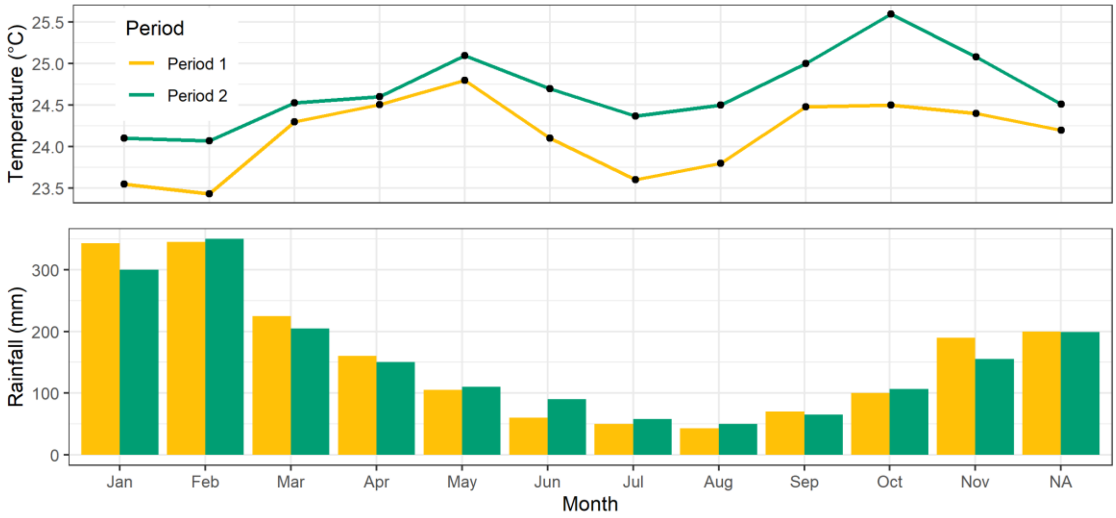


Figure 2. Climograph comparing two periods: 1991-2006 (yellow) and 2007-2022 (green). The top panel illustrates monthly mean temperature (°C), while the bottom panel shows monthly total rainfall (mm).

assess variations in the plant growth comfort index, as well as shifts in rainfall and air temperature patterns. The analysis was divided into two periods: 1991 – 2006 for the 1st period and 2007 – 2022 for the 2nd period. A correlation analysis was performed to examine the relationship between changes in rainfall or air temperature and maize productivity or production, employing the Pearson correlation model (Equation 2).

$$r = \frac{\sum_{i=1}^{n} X_i Y_i - \frac{1}{n}(\sum_{i=1}^{n} X_1)(\sum_{i=1}^{n} Y_i)}{\sqrt{\left(\sum_{i=1}^{n}(X_i)^2 - \frac{1}{n}(\sum_{i=1}^{n} X_1)^2\right)\left(\sum_{i=1}^{n}(Y_i)^2 - \frac{1}{n}(\sum_{i=1}^{n} Y_1)^2\right)}} \quad (2)$$

where: r = correlation coefficient; X_i = rainfall or temperature; Y_i = maize production or productivity data.

Finally, temporal correlations were analyzed for the period from 1991 to 2022 and spatial correlations were calculated for each sub-district.

3. RESULTS

3.1 Climate Characteristics

Karawang Regency has a tropical climate, with an average air temperature of 27 °C, an average relative humidity of 80%, and a duration of sunshine of 66%. The monthly rainfall ranges between 75 – 304 mm with the mean rainy days between 6 – 18 days per month. The annual rainfall is round 1823 mm, which is 28% lower to humid tropics (Lisnawati et al., 2022; Taufik and Haikal, 2024). The highest rainfall occurs in January, while the lowest occurs in September. A peak dry season normally happens in June-August (JJA) period, while wet season in December-February (DJF). The remaining six months is a transitional period, consisting of three months of transition from the dry season to the rainy season and three months from the rainy season to the dry season. Based on its climatic characteristics, Karawang Regency is suitable for maize cultivation as well as other crops such as rice and soya.

3.2 Detection of Change

We compared air temperature and rainfall for two periods namely 1991–2006 and 2007–2022 to detect any change in climate variable. Our preliminary analysis showed a substantial change in air temperature and rainfall over the past 32 years (Table A1). Air temperature has increased by 0.5 °C, while rainfall has decreased by 47.3 mm. The most significant decreased in rainfall occurred in January (the rainy season), while the largest increase was observed in June (the dry season).

However, there has been no change in the Oldeman climate classification regarding the number of consecutive wet months (BB) and consecutive dry months (BK). Karawang Regency retains an Oldeman climate type in the D2 classification, characterized by a consecutive BB range of 3 to 4 months and a consecutive BK range of 2 to 4 months. The D2 classification sustains one rice or secondary cropping season per year, depending on the availability of irrigation water.

3.3 Climograph's Changes

The results of the climograph, which illustrate the relationship between air temperature and monthly average rainfall from 1991 to 2022 in the study site are shown in Figure 2. The climograph has changed over this period. In the first period, the highest temperature

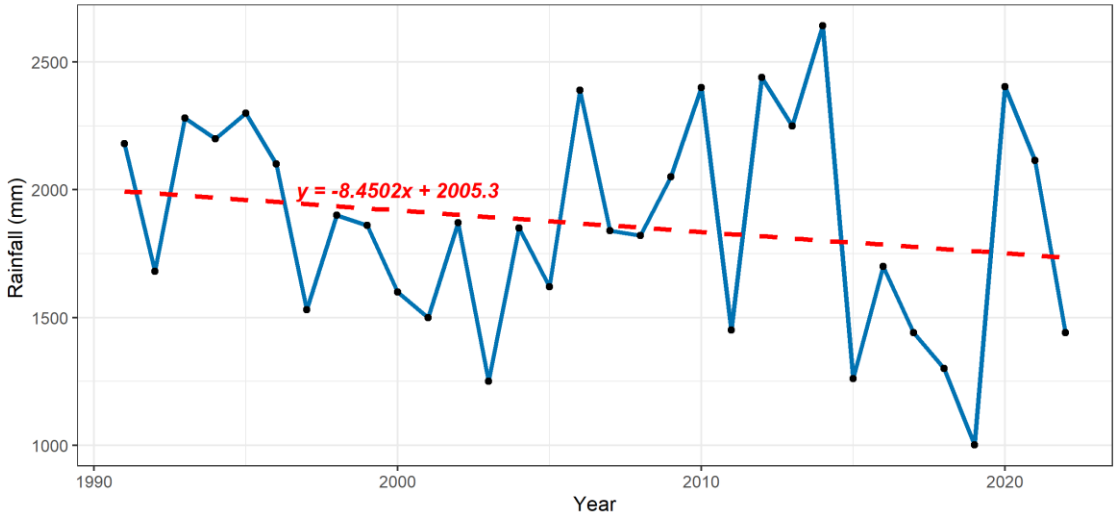


Figure 3. Annual rainfall trend from 1991 to 2022. Blue line indicates annual rainfall values, and the dashed red line represents the linear trend.

was recorded in May at 24.8 °C and the lowest in February at 23.5 °C. Rainfall exceeding 200 mm/month (wet months) occurred in January, February, March, and December, with the highest amount in February (339 mm). Rainfall below 100 mm/month (dry months) occurred in June, July, August, and September, with the lowest amount in August (40 mm).

In the 2nd period, the highest temperature occurred in October at 25.6 °C, while the lowest was recorded in February at 24 °C. Rainfall exceeding 200 mm/month (wet months) decreased in January, February, and March, with the highest value in February (344 mm). Rainfall below 100 mm/month (dry months) occurred in June, July, August, and September, with the lowest amount in August (53 mm). The climograph has shifted on the Y-axis, with the second-period graph positioned above the first, indicating an increase in the average temperature by 0.7 °C. Conversely, rainfall in Karawang Regency decreased in both periods, as shown by the shift from right to left on the X-axis. These changes in the climograph suggest a shift in the comfort index for maize plant growth, which impacts the maize's growth and yield.

3.4 Rainfall and Air Temperature Trends

The rainfall trend in the study site decreased from 1991 to 2022 as shown in Figure 3, with a decline of 8.45 mm/year. Rainfall in the region varied significantly over the past 32 years, with the lowest recorded in 2019 at 1001 mm and the highest in 2014 at 2642.78 mm. Rainfall during the rainy season (DJF) shows a decreasing trend, with an estimated annual decline of 4.77 mm. In contrast, rainfall during the dry season (JJA) exhibits an increasing trend, with an estimated annual increase of 2.42 mm.

The results confirmed previous studies indicating that some areas of Indonesia have experienced changes in annual and seasonal rainfall patterns (DJF and JJA) due to the influence of El Niño, La Niña, and climate change (Lestari et al., 2019; Rodysill et al., 2019; Ruminta et al., 2018). These changes in rainfall patterns affect crop production, particularly maize, which is sensitive to extreme climate events.

The air temperature has shown a tendency to increase by 0.04 °C per year (Figure 4). Over the past 32 years, the lowest temperature recorded was 23.8 °C in 1994, and the highest was 25.3 °C in 2017. The increase was predominantly influenced by changes in land use and cover, which drives higher surface temperatures (Rangel-Peraza et al., 2024). In 2020, the urban area of Karawang Regency was primarily covered by built-up land (including housing, industry, and roads), vegetation (such as grass, moorlands, golf courses, fields, and rice paddies), and open land (including land clearing, rice fields, and barren land. Regression modeling has shown that built-up and open land significantly influence surface temperature (Khalid et al., 2024).

3.5 Correlation of Climate Change Indicators with Maize Production and Productivity

The results of the temporal correlation analysis between climate indicators (rainfall and temperature) and maize production and productivity from 1991 to 2022 indicate weak and insignificant correlations. The correlation coefficients for rainfall and maize productivity, rainfall and maize production, air temperature and maize productivity, and air temperature and maize production were 0.09, 0.27, 0.24, and 0.07, respectively. These findings suggest that the relationships between

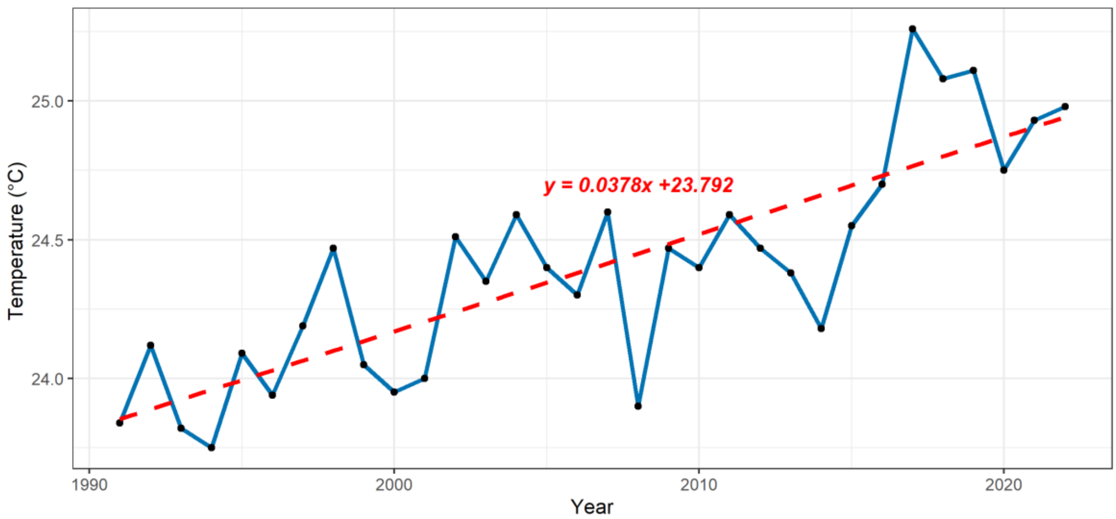
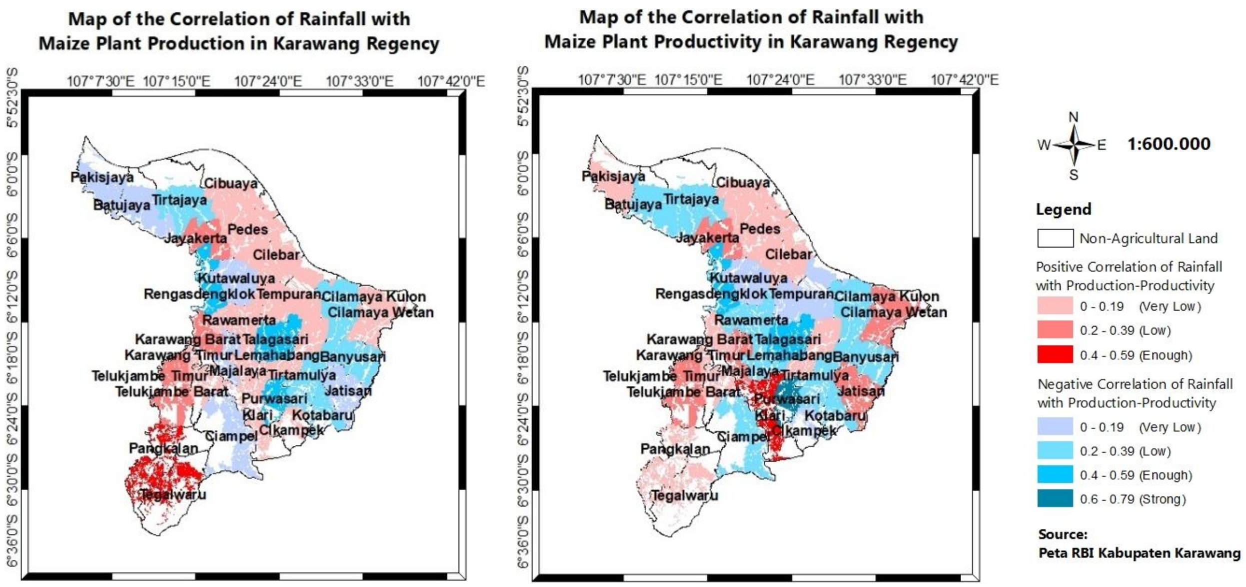


Figure 4. Annual air temperature trend for 1991-2022. Blue line indicates annual temperature values, and the dashed red line represents the linear trend.

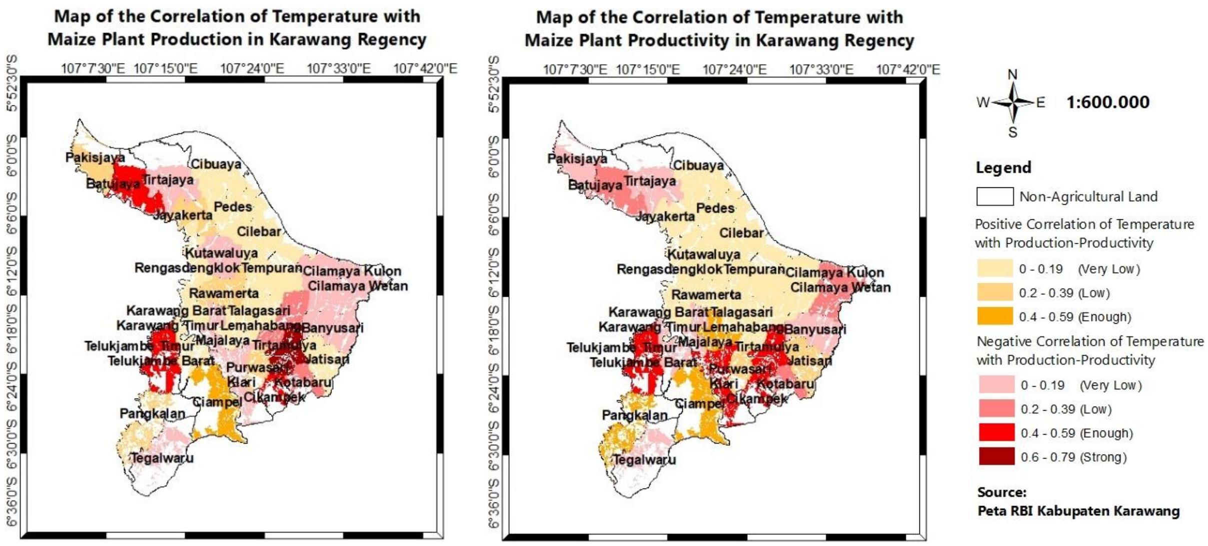
rainfall or air temperature and maize productivity or production were statistically in-significant. However, there is a slight indication that rainfall has a greater influence on maize production, while air temperature has a more noticeable effect on maize productivity.

The spatial correlation analysis between climate indicators (rainfall and air temperature) and maize production and productivity across 30 sub-districts in Karawang Regency for the period 2001–2014 is illustrated in Figures 5 and 6. Figure 5 depicts the spatial correlation map between rainfall and maize production. Overall, the correlation between rainfall and maize production in Karawang Regency is low, with correlation coefficients (r) < 0.40, except for Pangkalan and Tegalwaru, where r=0.59, and for Purwasari, Rengasdengklok, and Talagasari, where r=−0.59. The correlation coefficients across the 30 sub-districts range from 0.20 to 0.59, with an average of 0.31. The analysis indicates that changes in rainfall significantly impact maize production in the five identified sub-districts. The correlation between rainfall and maize productivity for the 30 sub-districts from 2001 to 2014 is presented in Figure 5. The correlation between rainfall and maize productivity for the medium category, where the correlation coefficient r=0.57, occurs in Klari, Rengasdengklok, and Talagasari sub-districts, while for



(a) (b)

Figure 5. Correlation coefficient map between rainfall and maize production (a) and between rainfall and maize productivity (b) in Kawarang Regency in 2001 – 2014.



(a) (b)

Figure 6. Correlation coefficient map between air temperature and maize production (a) and between air temperature and maize productivity (b) in Kawarang Regency in 2001 – 2014.

the high category, where the correlation coefficient r = 0.67 only occurs in Purwasari sub-district. The correlation coefficient for the 30 sub-districts of Karawang Regency ranges from 0.12 to 0.67, with an average of 0.35. This indicates that changes in rainfall indeed affect maize productivity in Karawang Regency. For temperature and maize production, the correlation is illustrated in Figure 6. A medium correlation category (r=0.40–0.47) is observed in Batujaya, Cikampek, West Telukjambe, and Ciampel sub-districts, while a high correlation category (r=0.62) is found in Tirtamulya sub-district. Across all 30 sub-districts, the correlation coefficients range from 0.19 to 0.62, with an average value of 0.30.

The correlation between air temperature and maize productivity in Karawang Regency varies but generally falls within the low correlation category (r<0.40). A medium correlation category (r=0.40–0.59) is observed in a few sub-districts, namely Telukjambe Barat, Klari, and Tirtamulya (Figure 6). Across the 30 sub-districts, the correlation coefficients range from 0.17 to 0.59, with an average of 0.32. These findings suggest that air temperature has a noticeable influence on maize productivity, though the degree of impact varies by sub-district.

4. DISCUSSION

The results show change in climate variables are detected for Karawang Regency. The increased trend of air temperature and the decreased trend of rainfall were detected in the study site. This may an early indication of climate change occurrence, but more studies are required such as through climate projection analysis (Hendrawan et al., 2024; McGregor et al., 2016; Try and Qin, 2024) using global climate data, such as CMIP6 (Kurniadi et al., 2024; Rettie et al., 2023), which is widely used.

The findings of this study address the limited availability of information on climate change and its relationship with location-specific maize production at both regency and sub-district levels in Karawang Regency. These results conform as critical inputs for farmers, agricultural extension workers, and policymakers, enabling them to anticipate and implement appropriate adaptations to mitigate the impacts of climate change on maize cultivation and development in Karawang Regency.

Based on the findings of this study, farmers, agricultural extension workers, and relevant stakeholders must continuously implement strategic adaptations to climate change to sustain or enhance maize production in Karawang Regency in the future.

5. CONCLUSION

The study concludes that Karawang Regency is experiencing climate change, represented by an increase in average air temperature of 0.56°C and a decrease in rainfall of 47.34 mm over the observed period. These changes are further reflected in a climograph shift, where the upward and leftward movement indicates a significant rise in temperature alongside relatively minor alterations in rainfall patterns. Additionally, the analysis reveals a notable relationship between climate variables and maize production and productivity. Rainfall demonstrates an average correlation coefficient of 0.31 with maize production and 0.35 with maize productivity, while air temperature shows an average correlation coefficient of 0.30 with maize production and 0.32 with maize productivity. These findings highlight the critical need for effective anticipation and adaptation strategies to address the impacts of climate change and ensure the sustainability of maize production in Karawang Regency.

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ANNEX

Table A1. Change in climate indicators in Karawang Regency.

Climate indicators	Change in climate indicators		Number of Changes
	1st Period (1991-2006)	2nd Period (2007-2022)	
Average Temperature (℃)	24,14	24,70	0,56 (+)
Average Rainfall (mm)	1889,57	1842,23	47,34 (-)
Wet Month (BB)	3	3	0
Dry Month (BK)	4	4	0
Januari Rainfall (mm)	338,35	299,08	39,27 (-)
February Rainfall (mm)	338,68	343,95	5,28 (+)
March Rainfall (mm)	219,05	209,35	9,71 (-)
April Rainfall (mm)	166,01	153,42	12,59 (-)
May Rainfall (mm)	105,66	110,01	4,35 (+)
June Rainfall (mm)	59,25	81,82	22,57 (+)
July Rainfall (mm)	51,01	60,91	9,90 (+)
August Rainfall (mm)	39,92	53,46	13,54 (+)
September Rainfall (mm)	73,79	69,10	4,69 (-)
October Rainfall (mm)	105,08	107,93	2,86 (+)
November Rainfall (mm)	195,29	156,25	39,05 (-)
December Rainfall (mm)	203,17	200,30	2,88 (-)
Oldeman Climate Type Classification	D2	D2	No change