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# Rice (*Oryza sativa* L.) production, productivity, and harvested area in Karawang Regency under extreme weather from 1991-2023

**Abstract.** Climate change occurred in Karawang Regency due to extreme weather events, which are included in the El Nino climate anomaly phenomenon. The existence of extreme weather events in Karawang Regency has decreased rice production, which is a climate-dependent crop. Based on this problem, a study was conducted to analyze the identification of extreme weather changes and correlation analysis of rice crops in Karawang Regency to see the magnitude of extreme weather changes and the influence of extreme weather elements on rice crops. The method used is a quantitative descriptive method by analyzing extreme weather changes, correlation analysis of extreme weather elements on rice plants (production, productivity, and harvest area), and correlation graphs of extreme weather elements with rice plants. Data was obtained from BPS, BMKG, and the Karawang Regency Agriculture and Food Security Office. The results showed that Karawang Regency experienced extreme weather changes due to climate change, namely an increase in the average maximum rainfall (1.78 mm), an increase in maximum temperature (0.76 °C), a decrease in minimum temperature (-0.57 °C), a decrease in wet spell for 3 days, and an increase in dry spell for 10 days. The impact of extreme weather change, namely the wet spell element, has a real significant correlation with a moderate level to a decrease in rice production and productivity.

**Keywords**: Climate change · Correlation · Extreme weather · Rice · Trend analysis

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## Introduction

Extreme weather events are part of the variability of the climate system, both in stable conditions and climate change, and negative impacts that arise, such as heavy rains, storms, and tropical cyclones (Vellore et al., 2020). These climate anomalies are becoming more frequent with more extreme seasonal conditions and prolonged durations that significantly impact agricultural production in many countries, including Indonesia (IPCC, 2001). Therefore, extreme weather changes can be attributed to climate change (Rehana et al., 2022). Climate indices that indicate extreme weather changes are generally related to rainfall and air temperature (Alizadeh-Choobari & Najafi, 2018). These two indicators have visible changes and can be identified regarding food cropping patterns (Ruminta, 2016).

One indication of climate change is changes in the pattern and intensity of various climate parameters, including erratic rainfall, intensity that tends to increase, and a shift in the beginning and length of the season that deviates or is extreme compared to normal conditions (Martel et al., 2021). Extreme weather informs the increasing weather and climate along with the increase of unusual natural phenomena (climate deviations) (Ummenhover & Meehl, 2017). The impact of extreme weather conditions is usually associated with increased rainfall intensity, the occurrence of hydrometeorological disasters such as flash floods and tidal floods, local storms, increased air temperatures, and drought (Kundzewicz, 2016). The impacts of extreme weather cause changes in rainfall patterns, the length of the rainy season, shifts at the beginning of the rainy season, and increased extreme weather events that seriously impact the agricultural sector, especially food crops (Mall et al., 2017).

The agricultural sector, which is highly dependent on climate, suffers losses due to extreme weather events. The agricultural sector in Indonesia is highly vulnerable to climate change, as climatic conditions affect production, yield quality, cropping patterns, and planting times (Rejekiningrum et al., 2022). One crop that is highly dependent on climate is rice (*Oryza sativa* L.). Rice strongly depends on climate elements, especially rainfall and temperature (Hussain et al., 2020). This dependence can be seen from the physiological impact of rice when rainfall decreases and temperature increases, namely the inhibition of the process of filling and ripening seeds, decreasing the rate of photosynthesis, which will affect the formation of carbohydrates, and reducing pollen viability, causing yield loss (Rahman et al., 2017). This extreme decrease in rainfall causes low productivity of rice plants, delays rice planting, decreases the area of planting and harvesting, disrupts the growth of rice plants because the average water needs of plants are reduced, and causes crop failure because rice plants are plants that are vulnerable to climate change (Hussain et al., 2020).

Extreme weather is divided into five indicators that significantly impact agriculture due to climate change: maximum rainfall, maximum temperature, minimum temperature, wet spells (consecutive rainy days), and dry spells (consecutive days without rain). Maximum rainfall can lead to flooding, waterlogging, and poor seed distribution, especially in direct-seeded rice fields. These conditions hinder germination, reduce plant populations, and increase vulnerability to disease, ultimately lowering rice yields (Darise, 2023). High maximum temperatures cause rice plants to suffer from heat stress, disrupting photosynthesis and respiration, particularly during growth stages, which can result in spikelet sterility, poor grain filling, and significant yield loss (Basak et al., 2013). Low minimum temperatures lead to cold stress during the reproductive stages (booting and heading), causing spikelet degeneration, incomplete panicle development, and impaired nitrogen uptake, all of which can drastically reduce yield (Beleten, 2019). Dry spells result in drought conditions, leading to water stress, particularly during the flowering and grain filling stages. This can cause poor seed development and, in severe cases, total crop failure (Molla et al., 2021). Wet spells, on the other hand, create waterlogged conditions, increasing the risk of root diseases and reducing oxygen availability to the roots. These effects can delay planting, hinder seedling establishment, and negatively impact crop growth and yield (Kaur et al., 2020). These five indicators are interconnected and collectively pose a significant threat to rice crops, particularly during their critical growth phases.

In addition to the decline in rice production and productivity due to extreme weather, this also impacts the planting season. Supposedly, three planting seasons can be carried out within one year, but currently, only two planting seasons can be carried out with planting times that are backward from the schedule (Wang et al., 2022). This extreme weather event needs to be a special concern because rice is the main food crop in Indonesia, especially in Karawang Regency, one of the most significant rice production contributing areas from West Java, which is the most significant contributor to rice production in Indonesia (Suliman & Setiawan, 2022). The decline in rice production in Karawang Regency continues to occur over the years. It can be seen that rice production in Karawang Regency has decreased, as seen in the data from 2023 to 2024, by 7.61%, from 1,131,977 tons to 1,045,879 tons (BPS, 2024). The decline in rice production is the impact of the problems in Karawang Regency, namely the problem of climate change due to extreme weather, including the El Nino event (Dewi et al., 2023).

To see the correlation of rice production, productivity, and harvest area in Karawang Regency with extreme weather events, it is necessary to analyze the data using Microsoft Excel from extreme weather elements, including maximum rainfall, minimum and maximum air temperature, consecutive rainy days (wet spell) and days without rain (dry spell), in the last 33 years (1991-2023) which are divided into 2 periods, namely the 1991-2006 period and the 2007-2023 period to determine the magnitude of extreme weather changes in Karawang Regency.

## Materials and Methods

The research was conducted in Karawang Regency, and data were taken from the Karawang Regency BMKG, the Karawang Regency Food Crops and Forestry Agriculture Office, and the Karawang Regency Central Statistics Agency (BPS). The research took place from January to March 2025. The design of the method used in this research is a descriptive method with a quantitative approach to analyze the impact of extreme weather events on production, productivity, and rice harvest areas in Karawang Regency. The data used are climate data such as temperature, rainfall, and extreme weather (maximum rainfall, maximum temperature, minimum temperature, dry spell, and wet spell for 33 years, namely 1991-2023, rice crop data from 1991-2023 (production, productivity, and harvest area). The obtained data was analyzed using Microsoft Excel 2019 and Minitab 19 statistical software to obtain extreme weather results and their correlation with rice plants in Karawang Regency.

The research data were analyzed using correlation and trend analysis at a 5% significance level:

1) Pearson correlation analysis between changes in temperature and rainfall in each sub-district in Karawang Regency.

$$r = \frac{\sum_{i=1}^{n} x_i y_i - \frac{1}{n}\left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i\right)}{\sqrt{\left(\sum_{i=1}^{n} (x_i)^2 - \frac{1}{n}\left(\sum_{i=1}^{n} x_i\right)^2\right)\left(\sum_{i=1}^{n} (y_1)^2 - \frac{1}{n}\left(\sum_{i=1}^{n} y_1\right)^2\right)}}$$

where :
r = correlation coefficient; xi = rainfall or temperature data for each sub-district in Karawang Regency; yi = production data, harvest area, and rice productivity of each sub-district in Karawang Regency.

2) Trend line equation (regression)

$$Y = b_0 + b_1 x$$
$$b_0 = \frac{\left(\sum_{i=1}^{n} y_i\right)}{\mathrm{n}}$$
$$b_1 = \frac{\sum_{i=1}^{n} (x_i y_i)}{\sum_{i=1}^{n} (x_i)^2}$$

where: Y = trend value of rainfall or temperature or maximum rainfall or maximum temperature or minimum temperature or wet spell or dry spell in Karawang Regency; $b_0$ = constant value, which is the value of Y when the value of X = 0; $b_1$ = the value of the slope of the line, which is the additional value of Y, if X increases by one unit; X = Year period value

## Results and Discussion

**Analysis of Extreme Weather Changes.** Karawang Regency in the 1991-2006 and 2007-2023 periods experienced extreme weather changes as shown in Table 1. The average maximum rainfall increased by 1.78 mm from the 1991-2006 period of 340.14 mm, increasing in the 2007-2023 period to 341.93 mm. The increase in maximum rainfall occurred due to an increase in Earth's temperature, which causes an increase in evaporation events and the volume of water in cloud formation, causing higher-intensity rain

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(Puspitasari et al., 2016). The maximum average temperature has increased and the minimum average temperature has decreased. The maximum average temperature from the 1991-2006 period of 35.32 °C increased by 0.76 °C in the 2007-2023 to 36.08 °C. Meanwhile, the minimum average temperature decreased by -0.57°C from 19.19 °C to 18.62 °C.

**Table 1. Changes in extreme weather in Karawang Regency in the period 1991-2006 and 2007-2023**

| Climate Indicators | Extreme Weather Change | | The Magnitude of Extreme Weather Change |
|---|---|---|---|
| | Period 1991-2006 | Period 2007-2023 | |
| Average Maximum Rainfall (mm) | 340.14 | 341.93 | 1.78 mm |
| Maximum Average Temperature (°C) | 35.32 | 36.08 | 0.76 °C |
| Minimum Average Temperature (°C) | 19.19 | 18.62 | -0.57 °C |
| Average of Wet Spell | 9 | 6 | -3 |
| Average of Dry Spell | 77 | 88 | 10 |

The increase in temperature, both maximum and minimum temperatures, is caused by global warming factors, with an increase in the average temperature of the Earth's surface within a specific period that occurred in Karawang Regency. In Indonesia, air temperature increased from the 1900s to the 20th century, increasing by 1.2°C (Siswanto et al., 2016). Apart from Karawang Regency, an increase in temperature has also occurred in the South Sumatra region, with an average increase in temperature of 0.5°C (Muharomah & Setiawan, 2022). The results of the study by Stocker et al. (2007) suggest that the climate will continue to warm or increase in temperature over a specific period due to the emission of gas and carbon dioxide, where the two elements will remain in the atmosphere for a hundred years even until nature can reabsorb these elements and the atmosphere returns to normal. This temperature increase occurred due to a massive increase in greenhouse gases such as $CO_2$ gas produced from fossil fuels and deforestation (Yoro & Daramola, 2020). This excessive concentration of greenhouse gases causes the sun's heat to be trapped in the atmosphere, which causes the temperature to rise.

Meanwhile, the average number of wet spells or consecutive rainy days decreased by -3 days, from 9 days in 1991-2006 to 6 days in 2007-2023. The decrease is inversely proportional to the increase in the average maximum rainfall, indicating that in Karawang Regency, the intensity of rainfall is increasing. However, the rainy time is getting shorter in both periods. The average number of dry spells or days without rain has successively increased in the two periods from the 1991-2006 period of 77 days to 88 days in the 2007-2023 period, with an increase of 10 days. The increase in dry spells indicates an increasingly dry climate in Karawang Regency.

**Correlation of Extreme Weather Changes to Changes in Production, Productivity, and Harvest Area of Rice Crops in Karawang Regency**. The results of the Pearson correlation of Karawang District (1991-2023) in Table 2 showed a positive and negative correlation relationship using a 5% significance level. From the table, it can be seen that the wet spell is significantly correlated with changes in the production and productivity of rice plants, with the results of negative correlation values in the relationship between the wet spell and the production and productivity of rice plants in Karawang Regency amounting to -0.49 and 0.49. The correlation value showed that the wet spell has a moderate relationship with production and productivity. The more consecutive rainy days that were not punctuated by dry days (wet spells) tended to decrease the amount of rice. Long-lasting wet spell conditions have the potential to cause waterlogging in agricultural land, reduce oxygen levels in the soil, and increase the risk of pest and plant disease attacks (Debangshi, 2021). In addition, too wet conditions can disrupt plant growth phases, especially in the early planting and flowering stages, which ultimately results in a decrease in yield (Ding et al., 2020). It can be indicated that prolonged wet conditions and low night temperatures can inhibit plant growth (Wahyuni et al., 2022). Consecutive rains lead to increased pest attacks and crop losses that can reduce rice production (Simkhada & Thapa, 2022).

**Table 2. The correlation between extreme weather and the production, productivity, and harvested area of rice crops in Karawang Regency**

| Correlation | Production (tons) | Productivity (q/ha) | Harvest Area (ha) |
|---|---|---|---|
| Maximum Rainfall (mm) | 0.16 | 0.12 | 0.27 |
| Maximum Temperature (°C) | 0.25 | 0.21 | 0.31 |
| Minimum Temperature (°C) | -0.13 | -0.04 | -0.23 |
| Wet Spell | **-0.49*** | **-0.49*** | -0.30 |
| Dry Spell | 0.07 | 0.06 | 0.19 |

Note: (*) Significant Correlation

Production changes have a medium correlation value with the wet spell. A wet spell is a consecutive period with several rainy days, usually associated with high rainfall and a more even water distribution. The negative correlation of wet spells to rice production results in a decrease in rice production due to the increase in wet spells. Too long wet spell conditions harm the growth of rice plants. Excessive rain can cause flooding, physiological stress on rice plants, and inhibit oxygen supply to rice roots, causing the death of rice roots and causing plants to die or harvest failure (Weng et al., 2017; Mahmood et al., 2019). Research in Subang showed that rice production decreased by up to 11.2% per year in several sub-districts, especially on rainfed land vulnerable to excess water due to intense wet spells (Ruminta et al., 2018).

In addition to production, productivity changes moderately correlate with wet spells. The negative correlation of wet spells to rice productivity results in a decrease in rice production due to the increase in wet spells. The wet spell can reduce the number of rice planting seasons from three times to twice a year because the land is flooded for too long, making it impossible to replant quickly (Yoon & Choi, 2020). In addition, if wet spells occur intensely, water is not absorbed optimally, which increases the risk of erosion and soil nutrient loss, so that rice productivity can decrease (Datta et al., 2017). Rice is so vulnerable to consecutive rainy days because it is tolerant to water but not to prolonged and deep inundation (Singh et al., 2017).

Between 1991 and 2023, rice cultivation in Karawang Regency faced severe challenges due to extreme wet weather conditions. This phenomenon triggered outbreaks of plant pests and diseases (PPDs), physical crop damage, and reduced planting intensity. Each rainy season or major flood event frequently led to brown planthopper infestations and bacterial leaf blight, resulting in crop failure across thousands of hectares of rice fields (Sogawa, 2014). Physical damage was also widespread, particularly during the 2013/2014 (7,700 ha) and 2023 (8,865 ha) planting seasons, where plant lodging occurred due to waterlogging (Tommi et al., 2015; Republika, 2023). These climatic disturbances, combined with infrastructure damage and land-use conversion, have significantly altered cropping patterns. The Cropping Index (CI), which previously reached CI 300 (three planting cycles per year) in irrigated areas during 1991–2005, has declined to CI 200 since the mid-2010s (Riadi, 2018). As a result, intensification strategies have shifted toward improving productivity per growing season.

Physiologically, rice plants are highly vulnerable to excessive rainfall or drought. When wet spell conditions lead to flooding in rice fields, a significant physiological impact is oxygen deficiency. This occurs because flooding induces hypoxia in the roots, reducing aerobic respiration and ATP production, which in turn disrupts root growth and function (Cai et al., 2025). Additionally, impaired gas exchange ($O_2$/$CO_2$) and chlorophyll degradation reduce photosynthesis. Turbid floodwater further reduces light penetration and photosynthetic efficiency (Gautam et al., 2015). In addition to physiological disruptions, nutrient availability is also impaired. Reduced potassium uptake results from impaired root function, and limited nitrogen availability is caused by anaerobic conditions that promote denitrification and inhibit nitrification (Tian et al., 2021).

Prolonged rainy seasons cause flooding, which disrupts the physiology and nutrition of rice plants, often leading to crop failure. Another significant impact of flooding is rice lodging, where plants fall over due to weakened stems that cannot support the weight of ripening grains (Liu et al., 2022). This condition arises during the grain-filling phase when stems begin to age. Excessive nitrogen (N) fertilization causes overly

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lush growth that weakens the stems, while increased fungal and bacterial activity further degrades plant tissues, accelerating lodging (Panja et al., 2024; Liu et al., 2024; Dong et al., 2023). This phenomenon is supported by research in Deli Serdang District, which found that in an analysis of the correlation between wet spells and rice productivity, yields tended to decrease, likely due to flooding and waterlogging (Chaniago, 2023). Wet spells also create ideal conditions for the development of rice pests and diseases, such as fungi and bacteria. These conditions increase the severity of disease outbreaks and further reduce yields, as rice plants are highly sensitive to pest and disease attacks (Asibi et al., 2019). Moreover, excessive moisture reduces the effectiveness of fertilization and pest control—nutrients are easily washed away, and pesticides become less effective (Kumar et al., 2021). As a result, crop yields decline despite stable or even increased levels of production inputs.

The observed correlation between wet spells and the decline in rice production and productivity in Karawang Regency highlights the urgent need for strategic adaptation over the next 15 years (2023–2038) to mitigate this issue. Strategic adaptation refers to deliberate adjustments, both environmental and social, in response to the adverse effects of climate change (Hessburg et al., 2021). Farmers and agricultural extension agents in Karawang can adopt several adaptive strategies, including the use of high-yield rice varieties that are tolerant to drought and flooding, such as Inpari 32, Inpari 48, and Cibatu 06 (Purbiati et al., 2024). In addition to varietal selection, appropriate cropping patterns—such as rice-rice-legume rotation—should be implemented, along with equitable irrigation water management across districts (Cox et al., 2025). Furthermore, Integrated Pest Management (IPM) should be promoted in accordance with recommendations from the Indonesian Center for Forecasting Plant Pests and Diseases (BBPOPT), including the implementation of coordinated pest control campaigns (Kusano et al., 2025).

**Trends and Distribution of Extreme Weather and Their Correlation with Rice Crop Production, Productivity, and Harvested Area in Karawang Regency**. Extreme weather events that correlate with rice cultivation include wet spells, which affect both rice production and productivity. As shown in Figure 1, the trend line illustrates the relationship between the number of wet spell days (consecutive rainy days) and total rice production (tons) in Karawang Regency from 1991 to 2023. An analysis of rice production reveals an average annual increase of 9,556.7 tons. Despite interannual fluctuations, this increase is largely attributed to farmers' use of high-yielding rice varieties such as Inpari 32, which is flood-tolerant, and Ciherang, which is drought-tolerant and highly productive (Aenunnisa et al., 2022). These varieties have demonstrated the ability to yield up to 9 tons per hectare, even during the dry season (Aenunnisa et al., 2022). In addition to varietal improvements, planting intensity has also increased, with farmers now practicing three rice cropping cycles per year, following recommendations from local government authorities (Mulya & Hudalah, 2024). This practice has significantly contributed to the upward trend in rice production in Karawang Regency.

Meanwhile, the number of wet spell days exhibits an inverse pattern compared to production. The annual average number of wet spell days in Karawang Regency from 1991 to 2023 has shown a declining trend of approximately 0.1319 days per year. This decline is associated with a reduction in annual average rainfall of around 47.3 mm over the 1991–2022 period, with the most significant decreases occurring during peak rainy months, such as January (approximately 39.27 mm) and March (approximately 9.7 mm) (Ruminta et al., 2024). Concurrently, the average temperature in Karawang Regency has increased by approximately 0.56 °C over the past 32 years (1991–2022), influencing evapotranspiration rates and soil moisture levels, and ultimately affecting the duration and intensity of the rainy season (Gunawan et al., 2024). The combination of reduced rainfall and rising temperatures has contributed to the declining trend in wet spell occurrences. The negative correlation between the number of wet spells and rice production is visually evident from the decline in production during years with a surge in wet spells. This phenomenon suggests that excessive consecutive rainy days can adversely affect total production—both through reduced yields per hectare and partial crop failures due to flooding, waterlogging, or disruption of critical plant growth stages (Bedane et al., 2022). Although the overall production trend shows an increase, the decreasing number of wet spells remains an external factor that may hinder the achievement of optimal rice yields.

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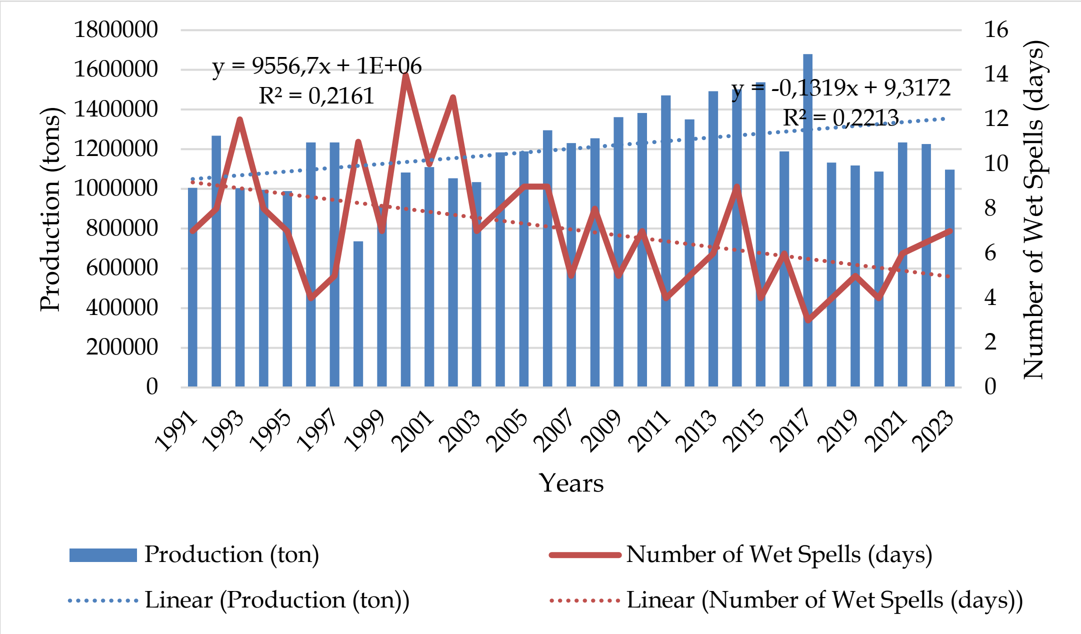


**Figure 1. Distribution of wet spells and their relationship with rice production in Karawang Regency**

In addition to its significant correlation with production, wet spells also show a significant correlation with rice productivity. Figure 2 illustrates the distribution of wet spells (consecutive rainy days) and rice productivity (q/ha) in Karawang Regency from 1991 to 2023. An analysis of rice productivity reveals an annual increase of 0.355 q/ha. This increase is attributed to a technical efficiency score of 0.9607, which is considered high, supported by factors such as expanded land use, the adoption of high-yielding varieties (Ciherang and Inpari 32), and the application of high-quality pesticides (Aenunnisa et al., 2022). Additionally, government intervention has played a significant role in enhancing rice productivity in Karawang Regency. This is evident through the provision of subsidized high-quality seeds, such as Inpari 32, and the distribution of modern agricultural machinery (e.g., rice threshers), which have helped farmers increase yields per hectare (Mulyani et al., 2020). The upward trend in rice productivity in Karawang Regency is therefore driven by improved technical efficiency, the use of superior rice varieties, and government support in the form of seed subsidies and agricultural infrastructure.

Meanwhile, the number of wet spells exhibits an inverse pattern with production, where the average annual wet spell duration in Karawang Regency from 1991 to 2023 shows a declining trend of -0.1319 days per year. This downward trend in wet spells is attributed to reduced rainfall and increased air temperatures, both of which are influenced by the ENSO (El Niño–Southern Oscillation) climate anomaly (Wang et al., 2017). ENSO has caused Karawang Regency to experience both El Niño and La Niña events (Frimansyah et al., 2022). The declining trend in wet spells is primarily driven by El Niño, which leads to prolonged dry seasons, less frequent rainfall, and reduced rainfall intensity—factors that shorten the duration and frequency of wet spells (Yang et al., 2021). The negative correlation between the number of wet spells and rice productivity is visually evident, with productivity declining in years when wet spells increase. This suggests that a higher number of consecutive rainy days (wet spells) tends to reduce rice productivity. Prolonged wet spells can lead to waterlogging in agricultural fields, lower soil oxygen levels, and increase the risk of pest and disease outbreaks (Sun et al., 2017). Moreover, excessively wet soil conditions can disrupt critical plant growth stages, particularly during early planting and flowering, ultimately lowering yields and interfering with the planting schedule, resulting in reduced rice productivity (Short et al., 2016).

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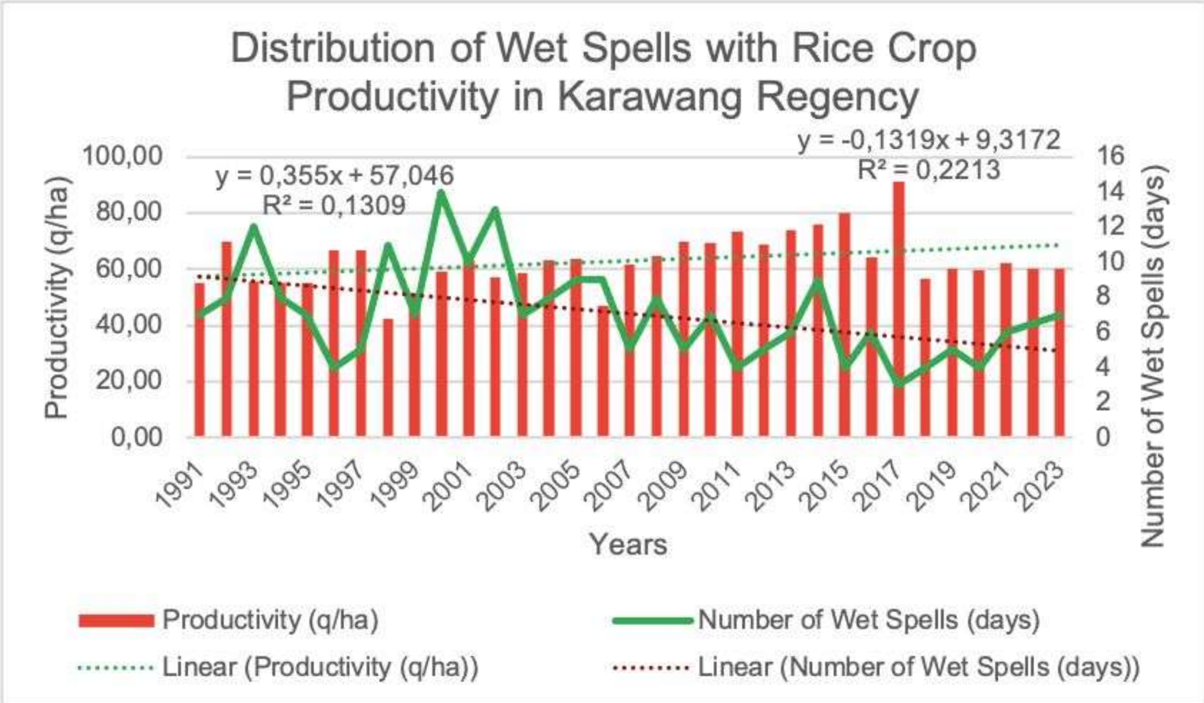


**Figure 2. Distribution of wet spells and their relationship with rice plant productivity in Karawang Regency**

## Conclusion

Karawang Regency is experiencing climate change that impacts extreme weather events, as seen in the increase in maximum rainfall, maximum temperature, and dry spells, then a decrease in minimum temperature and wet spells in 1991-2023. Extreme weather events in Karawang Regency during the wet spell element significantly correlate with changes in rice crop production and productivity, resulting in decreased production and productivity.

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