Building Resilience : Addressing Climate Change Impacts on Rice Production Based on Agricultural Infrastructure in West Java Province, Indonesia

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Abstract. Climate change threatens the sustainability of the agricultural sector and has the potential to affect food availability in West Java, Indonesia's rice production centre. This study aims to examine how agricultural infrastructure has developed over the past five years and how this has affected the vulnerability index. Climate, production, agricultural infrastructure and facilities data were collected from various sources, including the Central Statistics Agency, the Ministry of Agriculture, and the Directorate General of Agricultural Infrastructure and Facilities. The data were analysed to obtain Pearson correlation values and vulnerability levels based on the ratio of production inputs to harvested area. The results show that climatic elements affect rice production in West Java, especially rainfall (r = 0.82), which is negatively correlated with production. The increase in rainfall causes significant flooding, which leads to crop failure. Production inputs such as agricultural machinery, ponds and rehabilitated tertiary irrigation networks (RTIN) support production and mitigate climate impacts. Rice production has a high Pearson correlation with the vulnerability index (r =0.75). The vulnerability ratio for West Java in 2022 was 0.0015, which means it is classified as vulnerable.

1 Introduction

The greatest challenge for humankind today is adapting to climate change, which is growing more urgent. Threats posed by climate change to the agricultural sector include decreased harvest duration, salinization, increased pest attacks, changes in weed flora, and drought [1-3]. Studies show that climate change has a significant impact on the agricultural sector and economy [4-9]. In Indonesia, climate change results in high rainfall and a prolonged dry season that leads to crop failure [10], an increase in global temperatures, and a substantial rise in the number of natural catastrophes from 1245 to 3814 cases between 2009 and 2019 [11]. Overall, the agriculture sector, which produces food, is seriously threatened by climate change. Climate change will also affect food security because global population growth will result in rising food demand. Undisputedly, there is a connection between agriculture and

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climate change, and in recent years, the agricultural industry has been especially susceptible to the effects of climate change [12,13].

According to [14], climate change could threaten rice production sustainability by reducing rice production [15]. In particular, as shown by [16] study, climate change caused a 25% decline in rice production in Indonesia in 2014. Specifically, in rice cultivation, which relies on the availability of intensive irrigation, climate change affects the condition of the water resources [17]. Stakeholder involvement and a well-developed adaptation and mitigation plan are essential for facing climate change. The government's concern for anticipating and adapting to the impact of climate change has been reflected in the policies regarding the development of agricultural infrastructure and the efficient administration of water resources.

The Indonesian government has taken several efforts to adapt to climate change by building conservation infrastructure like reservoirs and rehabilitating tertiary irrigation networks [18]. Water storage structures serve as water harvesters and can supply water to agricultural land, particularly during the dry season. Water management technology is also required in the current irrigation network to help reduce water loss, particularly in the distribution where the water loss can reach up to 40%. Since 2014, the Directorate General of Agricultural Infrastructure and Facilities has implemented an adaptation strategy to cope with El Nino and La Nina. In 2018, 400 reservoir units totalling 8000 hectares of irrigation were constructed [19]. In terms of policies and programs, the government has developed the Agricultural Climate Information Network, Climate Field Schools, agricultural infrastructure, Development of Sustainable Food Home Areas, etc., to minimize susceptibility and the effects of climate change. The regulations contained in the Regulation of the Minister of Environment and Forestry (Permen LHK) No. 33/2016 are about Guidelines for Preparing Climate Change Adaptation Actions. Climate change adaptation policies aim to preserve national food security [20].

A study by [21] stated that irrigation modernization and good water management must be emphasized to anticipate the impacts of climate change. Another case study about the correlation between irrigation and climate change's adaptation strategy was conducted in Southern Italy by [22], stating that irrigation networks' susceptibility to climate change conditions and water loss will rise in the absence of effective water management and distribution systems. A study by [23] used the STREAM approach to analyze the effects of climate change and the availability of agricultural water in the Cimanuk watershed; the findings indicated that the agriculture water balance within the Cimanuk Watershed was in critical condition. Poor infrastructure was one of the reasons for vulnerability in the Hindu Kush Himalayan area, specifically susceptible to climate change [24]. In order to support food security, these conditions required developing protective infrastructure, such as updating and enhancing irrigation infrastructure [25]. However, studies that examined how agricultural buildings and infrastructure affected vulnerability value are still not given much attention.

This study seeks to address a research gap by assessing how the growth of agricultural infrastructure over the previous five years has affected the vulnerability index. Additionally, the impact of agricultural facilities and infrastructure—in this instance, reservoirs and the restoration of irrigation networks—is also noticeable in rice productivity and production.

2 Materials and method

2.1 Study site

The effect of climate change on rice production and the values of flood and drought susceptibility was observed in West Java Province, Indonesia. This area was chosen because it was one of the rice production centers with the highest contribution to rice production during the 2018 - 2022 period, amounted to 31% of the total production in Java and 16% of national production. The predominant climatic features of this region are equatorial monsoons and a continuous wet season. Two seasons are used to describe the climate: the dry season (April through September) and the rainy season (October until March). Three growing seasons are typical for rice, with one wet season crop and two dry season crops. In this area, there is roughly 2000-3500 mm of annual rainfall. The highest and minimum temperatures are 34.70°C and 19.20°C, respectively, with an average annual temperature of 26.14°C.

2.2 Data collection

The climate data, rice production, productivity data, harvested area, and agricultural infrastructure data were obtained from several sources. Observed climate parameters, such as rainfall and air temperature during 2018-2022, were collected from the Statistical Yearbook of Indonesia, BPS-Statistics Indonesia [26]. The same source goes for rice production, productivity data, and harvested area, while the data on infrastructure and facilities examined, such as agricultural machinery, data in reservoirs, and rehabilitation of tertiary irrigation networks, were collected from the Ministry of Agriculture and Directorate General of Agricultural Infrastructure and Facilities.

2.3 Data analysis

The data were processed by Microsoft Office Home and Student 2021 and presented in tables and graphs. Correlation of each observed data was performed by the Pearson correlation equation (Equation 1). The ratio of vulnerability to drought and flooding is calculated using Equation 2.

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

$$Vulnerability\ Ratio\ (VR) = \frac{(Agricultural\ Machinery\ (unit) + Reservoir\ (unit))}{Harvested\ Area\ (ha)} \quad (2)$$

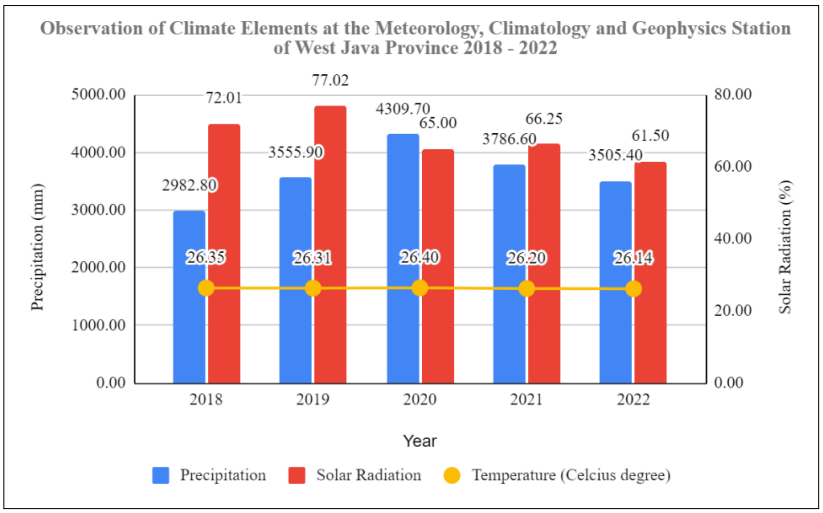
Vulnerability values were described as: (i) Vulnerable = <0.0026; (ii) Sufficiently vulnerable = 0.0026 - 0.0047; and (iii) Not Vulnerable = > 0.0047.

3 Result and discussion

3.1 Climate conditions and rice production in West Java Province in 2018 – 2022

Changes in the characteristics of various parameters or climate elements, such as precipitation, temperature and other climate elements, are affected by climate change. Figure

1 provides an overview of the annual precipitation, temperature and solar radiation for the years of 2018 to 2022. Compared to the first year of monitoring, precipitation has risen significantly from 2018 to 2022. While temperature has remained constant, solar radiation has also fluctuated slightly over the last five years. The results are consistent with the study by [27,28], which states that increasing temperatures, solar radiation and extreme



precipitation indicate that the global climate is changing. The three climatic factors mentioned above have affected agriculture and natural resources.

Fig. 1. Observation of Climate Elements at Meteorology, Climatology and Geophysics Station of West Java Province 2018 – 2022 (Source: Statistical Yearbook of Indonesia 2019-2023, BPS-Statistics Indonesia – processed).

During this period, rice production and productivity in the province of West Java were relatively stable, ranging from 9.0 to 9.6 million tonnes and from 56.5 to 57.5 qu/ha, respectively. This was confirmed by the statistics for the harvested area, which showed no significant changes over the previous five years (Fig. 2). However, there was a slight decrease in rice production from the first year of observation in 2018 to the current year, from 9.64 million tonnes to 9.43 million tonnes. In line with the decline in production and productivity, the area harvested decreased from 1.70 million ha to 1.68 million ha.

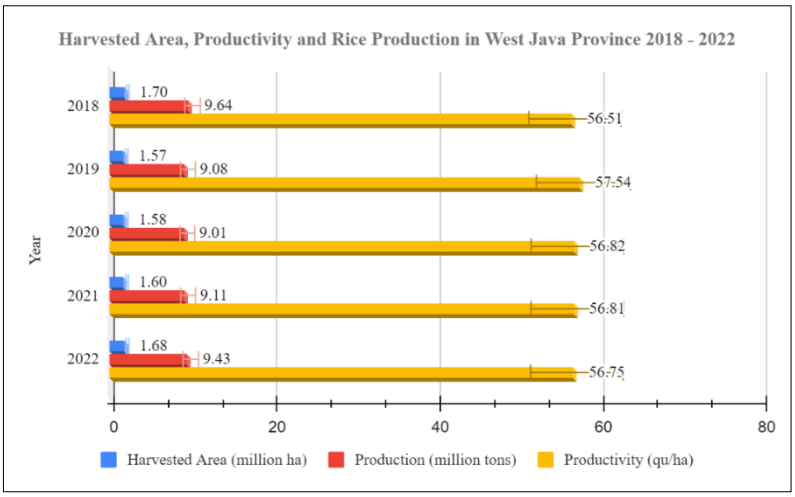


Fig. 2. Harvested Area, Yield, and Production of Paddy of West Java Province 2018 - 2022 (Source : Statistical Yearbook of Indonesia 2019-2023, BPS-Statistics Indonesia – processed).

In terms of climate, rainfall is affected by climate change, which also increases droughts and floods. Flooding and droughts increased and caused harvests to fail between 2017 and 2021. Less area is harvested due to this occasion. Figure 3. shows the annual floods and droughts that have affected rice yields in West Java.

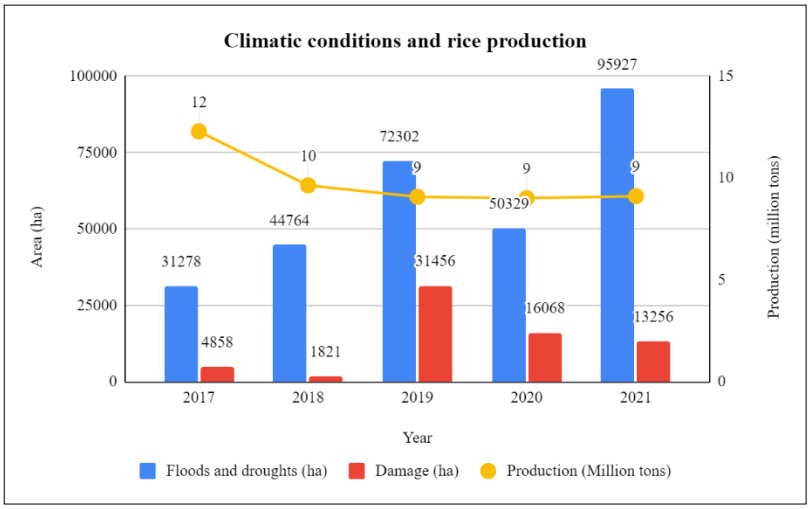


Fig. 3. Impact of Climate Changes on Rice Yield of West Java Province 2018 – 2022 (Source : Statistical Yearbook of Indonesia 2019-2023, BPS-Statistics Indonesia – processed).

Compared to the initial data in 2017, the total number of flood and drought cases in 2021 increased by about 67% and led to a 25% decrease in production. Based on a study by [29], crop losses were mainly caused by floods and droughts. Between 2015 and 2019, approximately 9.42 and 3.72 million ha of agricultural land in Southeast Asia were affected. As shown in a study by [30], there was a negative correlation between flood intensity and crop loss, with flood depth being one of the factors that significantly affected crop loss. In line with the findings of another study by [31], drought and flooding were two of the factors that significantly reduced rice grain yields.

3.2 Impact of changes in rainfall on rice production in West Java Province

Rice production in West Java is influenced by rainfall, which is one of climate elements that has been observed (Fig.4). In general, an increase in total rainfall from 2018 to 2022 led to a decline in rice output. In other words, there is a negative correlation between production and a given amount of rainfall. The Pearson's coefficient of correlation between these two measured parameters is -0.862. This value is an indication of a strong relationship between rainfall and rice production, or, alternatively, a decrease in rice production as a result of an increase in rainfall.

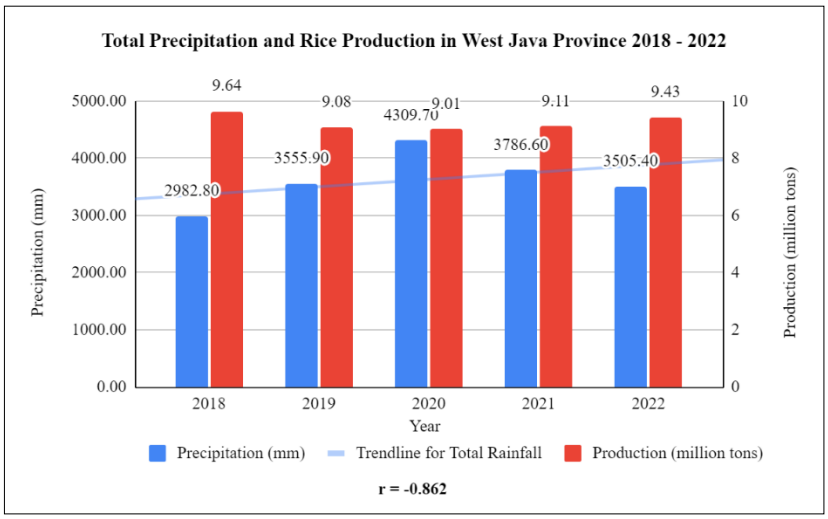


Fig. 4. Total Annual Precipitation and Rice Production in West Java Province in 2018 - 2022 (Source : Statistical Yearbook of Indonesia 2019-2023, BPS-Statistics Indonesia – processed).

A study by [32] showed that high precipitation affected panicle filling and increased the number of unfilled grains. Although rainfall is beneficial in terms of increase in water availability, excessive amount of rainfall will be an abiotic stress on rice plants. The result also showed that heavy rainfall had an effect on panicle filling and an increase in the number of unfilled grains. The same result is found in [33], where Feasible Generalized Least Squares (FGLS) showed that increasing temperature and precipitation adversely affected rice production.

3.3 Input productions and paddy production

Over the past five years, there has been a trend of decreasing overall allocations of agricultural machinery (Figure 5). In 2018, the allocation of agricultural machinery almost reached 6000 units, and by 2022, it had decreased by 40%. The fulfillment of the quota for the region and the budget for this concern, which was decreasing and being allocated to other development goals, were the main causes of this reduction. The Pearson correlation values for agricultural machinery and reservoir factors on rice production are 0.79 and 0.80 respectively. These two components are important production inputs for increasing rice production in West Java Province.

In terms of water management, the government also supports the construction of conservation infrastructure such as reservoirs and the rehabilitation of tertiary irrigation networks (RTIN) in West Java Province, even though this region receives the highest rainfall in the country. The realization of the construction of the reservoirs and the RTIN has varied between 2018 and 2022. On average, approximately 25 - 37 reservoirs are developed each year. 154 reservoirs have been constructed in the last five years. The RTIN serves an area of 12,350 hectares by 2021, reaching a peak of 23,400 hectares before beginning a decline in 2022.

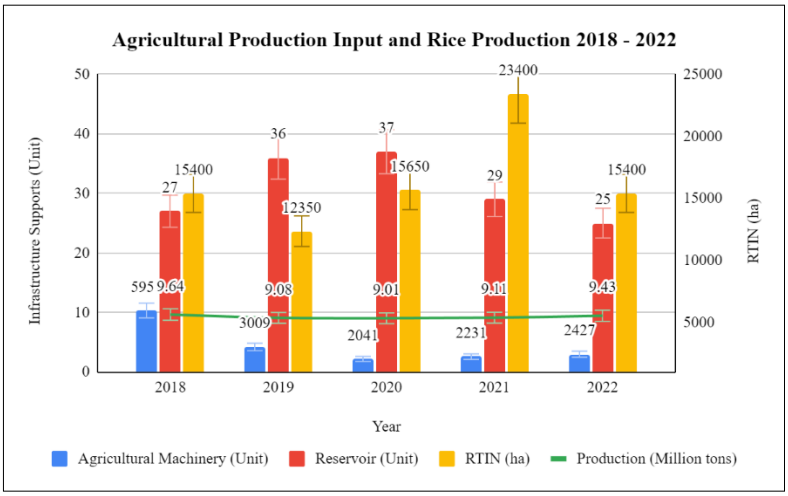


Fig. 5. Agricultural Production Input and Rice Production in West Java Province in 2018 – 2022 (Source: Agricultural Infrastructure and Facilities Statistics 2017-2021 and Directorate Irrigation Data 2022 - processed).

Research by [34] points out that technology adoption is very important in mitigating climate change. In addition to efficiency gains, agricultural mechanisation, such as the use of trashers, direct seeding of rice and combined harvesters, also increases rice production. The level of mechanisation significantly affects rice production, especially in developing Asian countries [35]. This is in line with the study by [36], which shows that the use of a combined harvesters can significantly increase the productivity by 0.16 t/ha and can also increase the profit by 40%. Besides mechanisation inputs, water availability and management are one of the production inputs that play a role in increasing paddy production and farm profits. It also has the potential to increase cropping index along with other components such as improved varieties and best management practices of nutrient [37].

3.4 Level of vulnerability to climate change impacts

The ratio of the vulnerability of the agricultural sector to the impacts of climate change in West Java has been dropping over the last five years. The lower the value of the ratio, the more vulnerable the area to climate change. Values below <0.026 are categorised as vulnerable. In 2019, there was a sharp decline to 0.0019 from 0.0035 in 2018. The value of 0.0015 in 2022 is an indication that the province of West Java is highly vulnerable to the impacts of climate change. With a correlation value of 0.75, the results of the Pearson correlation analysis show that the vulnerability ratio has a significant impact on production.

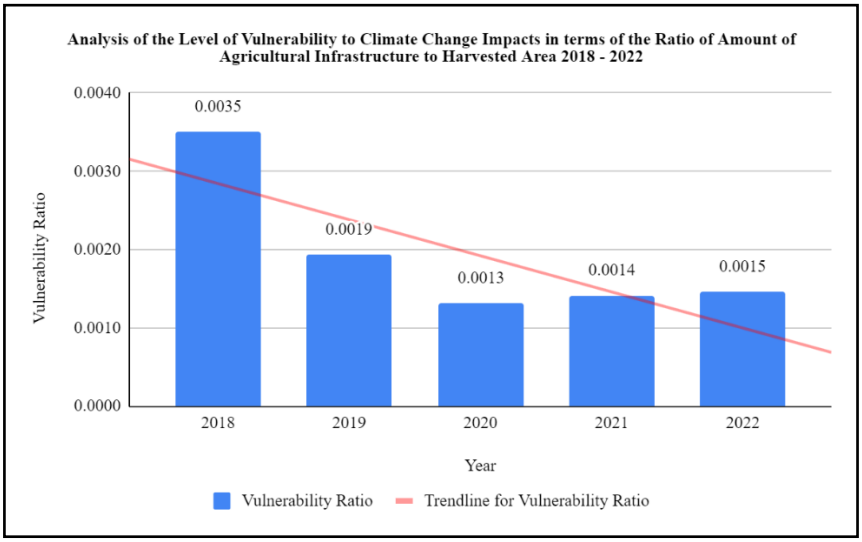


Fig. 6. Ratio of vulnerability to climate change impacts in West Java Province in 2018 - 2022 (Source : Agricultural Infrastructure and Facilities Statistics 2017-2021 and Directorate of Irrigation Data in 2022 - processed).

Based on the Seemingly Unrelated Regression (SUR) analysis conducted by [32], it was found that West Java Province was the area most affected by climate change. This result also supports a recent study conducted by [38], which found that agricultural intensification through mechanisation is a strategy to mitigate climate change, although it is still implemented by few farmers. The findings suggest that there is a need to improve farmers' knowledge and technological skills related to climate change and its impacts, to develop effective adaptation and mitigation measures, and to build climate resilient infrastructure in the agricultural sector. According to [39], building dams or reservoirs in water management is one of the efforts aimed at reducing vulnerability to climate change impacts. This mitigation can be achieved through structural as well as non-structural aspects.

4 Conclusion

Climate change affects the agricultural sector in West Java Province during the period of 2018-2022. Climatic elements such as rainfall, percentage of solar radiation, and temperature fluctuate from year to year. Changes in climate aspects contribute to the occurrence of floods and droughts, with an increase in the number of extreme events in 2021, which resulted in crop failures. Government interventions not only help increase production, but also mitigate the effects of climate change by supporting the agricultural machinery, building reservoirs and rehabilitating irrigation networks. Regarding vulnerability, based on the ratio of agricultural infrastructure to cropland, West Java is classified as an area that is vulnerable to climate change impacts. Based on this study, it is necessary to build infrastructure that will help to improve water management and also increase agricultural mechanisation.

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