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Vulnerability and risk analysis of climate change impacts on rice production (*Oryza sativa* L.) in Majalengka regency

Abstract. Climate change, especially temperature and rainfall shifting can be a threat to the agricultural sector, i.e., the decrease in rice yields in Majalengka Regency as the West Java rice production center. As an anticipatory measure to deal with that problem, a study is needed regarding the level of hazard, vulnerability and risk of climate change impacts in Majalengka Regency. This research aims to identify climate change and examine the level of hazzard, vulnerability and risk of the impact of climate change on rice production in each sub-district in Majalengka Regency. The method used in this research is descriptive quantitative. The data used in the analysis of the level of hazard, vulnerability and risk of climate change include temperature, rainfall, production, productivity, planting area, harvested area and farmers' socio-economic data obtained from Statistics Indonesia; Meteorology, Climatology, and Geophysical Agency; Agriculture Office of Majalengka Regency and other relevant sources, while farmer interview data were used in analyzing strategic adaptation options. The results of the study stated that areas with a very high potential risk of decreasing rice production (Risk Index or RI > 0.80) were in Kertajati District; the risk level of rice production in the high category (RI 0.61-0.80) was in Bantarujeg and Ligung Districts. Meanwhile, areas with a very high level of risk of decreasing rice productivity (IR) > 0.80) are in Bantarujeg District; high-risk level (IR 0.61-0.80) was in the Districts of Lemahsugih, Malausma, Argapura, Kertajati, Jatipuh and Ligung. The adaptation efforts that can be made to reduce the risk of decreasing rice production are the use of superior seeds, crop rotation, intermittent irrigation systems, acceleration of land preparation by mechanization, application of the jajar legowo cropping system, and integrated pest management measures.

Keywords: Climate change · Production decline · Risk · Strategic adaptation

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Introduction

Climate change is a condition characterized by erratic weather phenomena causing changes in world climate patterns (Bantacut, 2014; Surmaini et al., 2024). New climate change can be known in the long term, although slowly, climate change has a big impact on life. A report issued by Intergovernmental Panel on Climate Change (IPCC, 2013) explains that air temperature has increased by 0.8˚C in the last century so conditions are warmer than in the previous decade.

Based on the modeling scenarios reviewed by the IPCC, at the end of 2100 it is predicted that there will be an increase in the global average temperature of 1.8-4˚C compared to the average temperature in 1980-1999 (IPCC, 2013). An increase in temperature can be caused by human activity by adding greenhouse gases to the atmosphere (Kweku et al., 2018). These conditions result in emissions that have been previously released and carbon dioxide will remain in the atmosphere for a hundred years or more before nature can absorb it again so that the climate continues to warm (Ricke & Cardeira, 2014).

The agricultural sector is very vulnerable to climate change because it is related to cultivation systems such as cropping patterns, planting time, production and product quality which have a direct impact on national food security (Enovejas et al., 2021; Irham & Azhar, 2023). In Indonesia itself, the climatic factors that are the main obstacles in agriculture are temperature and rainfall, this is due to the geographical factors of the Indonesian archipelago, where the altitude causes climate conditions to vary greatly from one place to another (Ikhwali et al., 2022; Beding et al., 2021; Kirono et al., 2016).

Rice plants (*Oryza sativa* L.) are a staple crop for almost the entire population in Indonesia, so if production declines due to climate change it will disrupt food security. According to the publication of the Statistics Indonesia (2021), rice production in Indonesia in 2021 was 54.42 million tons of dry milled grain (GKG), a decrease of 233.91 thousand tons (0.43%) compared to production in 2020. Factors that can affect the decline in rice production every year are the harvested area, where the harvested area of rice in 2021 is 2.3% compared to the previous year.

Majalengka Regency is one of the rice production centers in West Java, but every year its production fluctuates. According to the Publication of the Statistics Indonesia in 2021, unhulled rice production is only around 681,709 tons/ha, a decrease of 6% compared to 2020 (Statistics Indonesia, 2021). Rice production in rainfed land has a similar fate, in 2018 production decreased by 35% compared to 2017. This is in line with the reduced planting area and harvested area of rice in rainfed land, where in 2018 the rice planting area was 2,048 ha, reduced by 270 ha compared to the previous year (Statistics Indonesia, 2018).

Given the magnitude of the impact of climate change, especially in the Majalengka Regency area which is one of the rice-producing areas in West Java, it is necessary to have a prediction and anticipation as an effort to minimize losses that can be done by making a study of how the level of vulnerability and risk of decline or failure of rice production due to local climate change. This study consists of three analyses, namely hazard, vulnerability, and risk or even the failure of rice production due to climate change in Majalengka Regency. Adaptation or adjustment efforts are made in anticipation of possible impacts.

Materials and Methods

This research was conducted in October 2022-March 2023. This research was conducted using a descriptive method with a quantitative approach to analyze the impact of environmental changes on rice production in Majalengka Regency. The use of this research method was carried out because several data obtained were the results of field observations (quantitative and qualitative) which were analyzed statistically, the results of which were interpreted in the form of tables and spatial maps.

The data used in this study were climate data (temperature and rainfall) from 1990-2021, data on rice production and productivity, rice land area, and socio-economic data of farmers such as number of farmers, education level, and farmer income from 2007- 2021 collected from archives such as Statistics Indonesia, Agricultural Office of Karawang, and Meteorology, Climatology, and Geophysical Agency. Surveys and interviews were carried out as supporting data to find out how the rice planting or cultivation activities were carried out by farmers in Majalengka Regency. Interviews were conducted using the method of in depth interview, as many as 5 rice farmers were interviewed in different areas, namely in the Districts of Majalengka, Cigasong, Dawuan and Kasokandel. The head of the Majalengka District Counseling Division and Agricultural Extension Officers in Majalengka and Dawuan Districts were also interviewed to obtain supporting information and confirmation of cropping conditions and adaptation strategies undertaken by farmers in Majalengka District to deal with climate change.

The data was analyzed using Minitab 19 and Microsoft Excel 2016 to obtain the magnitude of climate change, hazard index, vulnerability index and risk index. The analysis results were interpreted and presented in the form of a spatial map using the software ArcGIS

Hazard Analysis. In hazard index analysis, decreased rice production due to climate change is reflected in reduced crop productivity, crop failure, crop failure, and reduced land area (Ruminta *et al.*, 2017; Akmaliam, 2022**;** Jamil et al., 2023).

Rice Yields. The relationship between an increase in temperature and an increase in plant respiration leading to a decrease in crop yields can be written using the equation of Temperature Quotient, where the rate of respiration doubles for every 10˚C rise in temperature.

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

An increase in temperature resulting in a decrease in yield as indicated by an increase in respiration can be written using the following formula.

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

Where: T = temperature (°C); ΔYp_1 = yield reduction potential due to plant respiration (tonnes/ha); Y_0 = crop production before temperature rise (tonnes/ha); Q_{10} = temperature quotient at the temperature after an increase in temperature; Q_{10o} = temperature quotient before an increase in temperature (initial temperature).

Higher temperatures lead to shorter plant life, lower plant biomass, and ultimately reduce yields. Handoko et al. (2008), said that the relationship between the decrease in yield caused by the plant age due to an increase in temperature, can be expressed by the following equation:

$$\mathbf{Yp_2 = Y_0(T_0 - T_b)/(T - T_b)}$$
$$\mathbf{\Delta Yp_2 = Y_0 - Yp_2}$$

Where: ΔYp_2 = yield reduction potential due to decreased plant age (tonnes/ha); Y_O = crop production before temperature rise (°C); T_O = initial air temperature (°C); T = air temperature after temperature rise (°C); T_b = plant base temperature (°C).

(b) Effect of rainfall on rice yields. Assuming that the rainy season is evenly distributed throughout the rice growing season, the relationship between rainfall and yield can be expressed using the following equation:

$$\mathbf{Y = K \times P}$$

Where: Y = rice crop yield (tonnes/ha); k = parameters (tonnes/(ha.mm)); P = rainfall (mm/season).

Based on this equation, changes in rainfall that have the potential to cause drought as well as flooding will result in a decrease in rice crop yields which is written as follows:

$$\mathbf{\Delta Yp_3 = k \times \Delta P}$$

Where: ΔYp_3 = potential decrease in rice yields (tonnes/ha) due to drought; k = parameters (tonnes/(ha.mm)); ΔP = change in rainfall (mm/season).

Thus, the effect of changes in air temperature and rainfall on the decrease in crop yields can be written with the following equation.

$$\mathbf{\Delta Y_a = max\,(\Delta Yp_1, \Delta Yp_2, \Delta Yp_3)}$$

Where:Y_a = decrease in crop yield due to increase in air temperature (tonnes/ha); ΔYp_1 = yield reduction potential due to plant respiration (tonnes/ha); ΔYp_2 = yield reduction potential due to decreased plant age (tonnes/ha); ΔYp_3 = potential decrease in rice yield (tons/ha) due to drought.

Vulnerability Analysis. Weis et al. (2016) stated in his research that the vulnerability of plants to climate change can be assessed using three components: exposure (E), sensitivity (S), and adaptive capacity (AC).

$$\mathbf{V = \frac{E \times S}{AC}}$$

Where: V = vulnerability; E = exposure; S = sensitivity; AC = adaptive capacity

Indicators such as exposure (E) are components of the agricultural sector that are affected by climate change, such as land area and number of farmers. Sensitivity (S) describes how agriculture responds to climate change, for example, such as land type and altitude (m asl). Adaptation Capacity (AC) is represented by the education level of farmers and farmer income.

Risk Analysis. The risk of decreasing rice production due to climate change can be interpreted as a potential that can cause negative impacts/losses presented as a threat to decrease food production (Lujala et al., 2015). Calculation of risk and climate change is calculated using the following formula:

$$\mathbf{R = H \times V}$$

Where: R= Risk; H =Hazard

Results and Discussion

Changes in Temperature, Rainfall, and Oldeman Climate Types. Table 1 shows that Majalengka Regency experienced an increase in air temperature of 0.33°C, where the temperature in Majalengka Regency in the 1990-2005 range was 27.16°C, then increased to 27.49°C in the 2006-2021 period. That way, Majalengka Regency has experienced climate change due to the impact of global warming, in which in Indonesia there has generally been an increase in temperature of 0.1°C/year since 1990 (Didiharyono et al., 2022; Irawadi et al., 2023; Maheng et al., 2023).

Table 1. Magnitude of climate change

Climate Indicator	Climate change		Magnitude of Change
	Period 1990-2005	Period 2006-2021	
Average Air Temperature (°C)	27.16	27.49	0.33
Average Amount of Rainfall (mm)	2683.8	2627.4	56.4
Oldeman Classification Types			
Consecutive Wet Months	4	4	0
Dry Month in a row	4	5	1
Oldeman's classification	D3	D3	No change

The results of the analysis also show that the annual rainfall in Majalengka Regency has decreased by 56.4 mm from period 1 (1990-2005) to period 2 (2006-2021). Changes in the amount and pattern of rainfall can occur due to climate change, in line with this it is known that rainfall in western Indonesia tends to decrease by around 135 mm/year to 860 mm/year, besides that the Greater Malang area of East Java has experienced a decrease in rainfall. around 0-550 mm after an increase in air temperature (Ruminta et al., 2018). Besides that, the decrease in rainfall in the 2006-2021 period did not change Oldeman's classification in Majalengka Regency because changes in rainfall tended to be small.

From 1990-2005 Majalengka Regency was included in the D3 agro-climatic zone with 4 wet months and 4 dry months. In the 2006-2021 period it was included in the D3 agro-climatic zone, but experienced an addition of 4 dry months to 4 wet months and 5 dry months. In relation to agriculture, especially food crops, the type of agro-climatic zone D3 means that it is possible to plant rice once and plant crops once, but depends on the supply of irrigation water (Kusumasari, 2016).

Changes in the Climogram of Majalengka Regency. The following is the result of a climogram analysis of Majalengka Regency in the 1990-2005 and 2006-2021 periods (Figure 1). In the period 1990-2005 the maximum air temperature occurred in October of 28.42°C, while rainfall above 200 mm occured in January, February, March, April, November, December, while the highest rainfall was in January of 497.3mm. Likewise, in the 2006-2021 period, the highest temperature was in October at 29.07°C with the highest rainfall occurring in March at 431.84 mm, while rainfall above 200 mm occurred in January, February, March, April, November, and December. In general, rainfall in Majalengka Regency is characterized by (i) high rainfall intensity from November to March influenced by the Asian Monsoon which is humid and gives a lot of moisture into the air, and (ii) low rainfall, leading to dryer condition on May-September, due to the Australian Monsoon (Sun et al., 2020).

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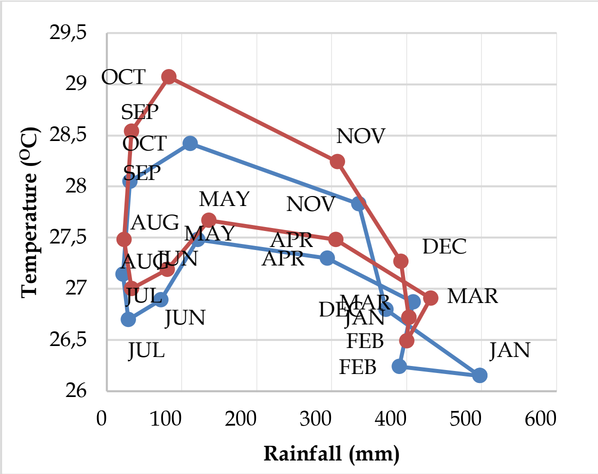

Figure 1. Climogram of Majalengka Regency

The results of the graphs described above can be concluded that in the period 1990-2005 to 2006-2021 the average air temperature increased by 0.33°C which is marked by the movement of temperature numbers towards the Y axis, while rainfall fluctuates and tends to decrease as in January from the 1990-2005 period to the 2006-2021 period decreased by 94.675 mm, which is indicated by the displacement of the value to the left from the x-axis direction. That way, high temperatures are not directly proportional to increased rainfall, in other words, in Majalengka Regency, certain months have high temperatures but decreased rainfall (Ruminta et al., 2024).

Hazard of Decreasing Rice Production in Majalengka Regency. From the results of the analysis, it appears that Majalengka Regency has the potential to reduce rice production from very low to very high levels. The area with the highest potential for a decrease in production is in Kertajati District, namely as many as 4364.03 tons, while the index for potential decline in rice production at a high level was in the Districts of Jatitujuh and Ligung with a decrease in production of 2663.77 tons and 3428.43 tons. The sub-districts of Lemahsugih, Bantarujeg, Maja, Palasah, Jatiwangi and Sumberjaya are in areas with a moderate decrease in rice production with an average decrease of 1960.84 tons, then other areas are in the low and very low categories with a potential decrease in rice production of <1700 tons. Thus, the potential danger of decreased rice production in Majalengka Regency is dominated by the low and very low categories. The magnitude of the potential hazard of decreased rice production in each sub-district of Majalengka Regency is an average of 6%.

The amount of air temperature is directly related to plant metabolic processes such as respiration, respiration will increase if the air temperature increases (Gudasz et al., 2021). Majalengka Regency itself in the dry season will be drier. This can cause a decrease in yields in rice plants, besides that, an increase in air temperature can also increase water vapor pressure which risks the wilting of plants. The wilting of plants occurs due to a decrease in the water potential in the leaves, so in rice plants, it can cause a reduction in the number of rice plant tillers, delayed flowering and a reduction in the number of productive tillers (Jung et al., 2015; Tun et al., 2021). The distribution of hazard levels and the complete decline in rice production is shown in Figure 2.

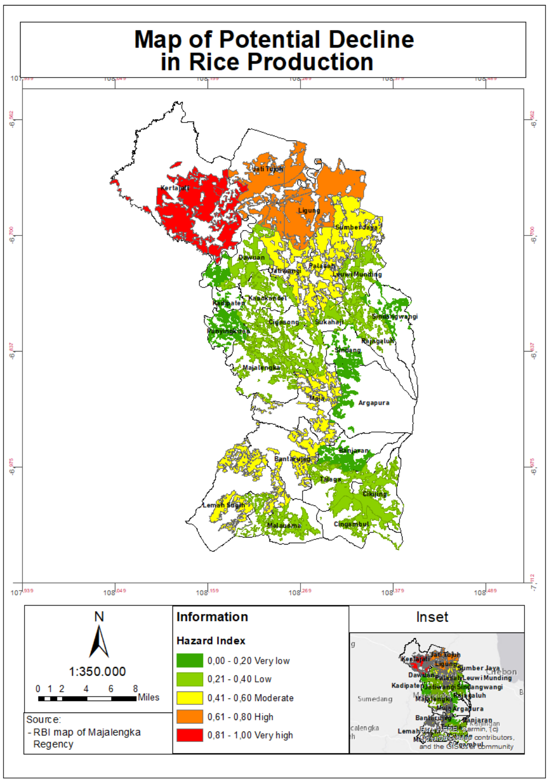

Figure 2. Distribution map of production decrease hazard potential

Hazard of Decreasing Rice Productivity in Majalengka Regency. The potential hazard of decreasing rice productivity in each district in Majalengka Regency is very high in all regions. The sub-district that has the highest potential is Sumberjaya, which has an index of 1.00 with a potential decrease in rice of 5.31 quintals/ha. This is because Sumberjaya District has the highest productivity, namely 66.31 quintals/ha, so with the same changes in temperature and rainfall the decrease in productivity is greater. Altitude also affects air temperature, where the lower the elevation, the air temperature rises and vice versa. Sumberjaya sub-district itself is located in the lowlands with an altitude of 36 m above sea level (lower than other sub-districts), so the potential for decline is greater. The potential for productivity decline in each sub-district in Majalengka Regency is an average of 8%. The following is the distribution of the level of productivity hazard in Majalengka Regency which is shown in Figure 3.

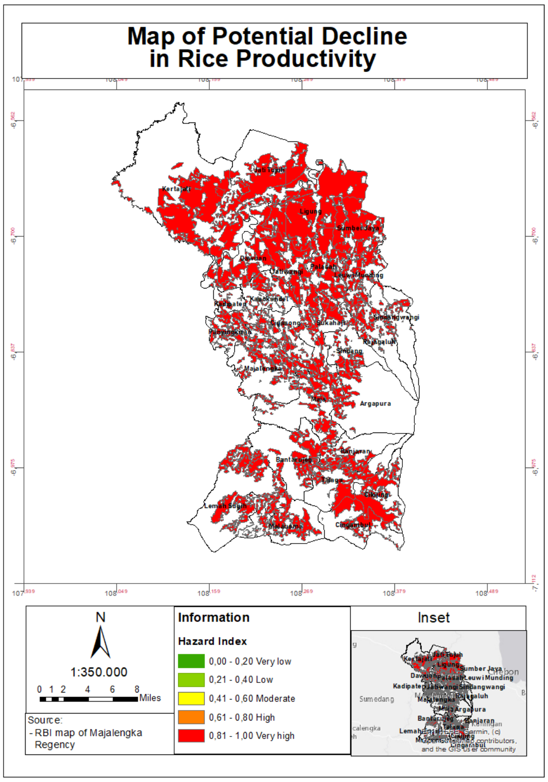

Figure 3. Potential hazard distribution map for decreased productivity

Potential Vulnerability to Decreasing Rice Yields. From the results of this analysis it can be seen that the area with the highest vulnerability index is only found in Bantarujeg District with an index of 1.00. Areas that fall into the high vulnerability category are the Districts of Lemahsugih, Malausma, Argapura, Kertajati, Jatitujuh and Ligung with an index of 0.61-0.70. Meanwhile, other areas in Majalengka Regency are dominated by low and very low vulnerability categories with an index of 0.04-0.35. Bantarujeg District has a very high level of vulnerability, this is noted from the high level of exposure and sensitivity when compared to the level of its adaptive capacity. Bantarujeg District has an exposure index of 0.69 and a sensitivity of 0.65 which is higher than its adaptive capacity index value of 0.27, as shown in Figure 4.

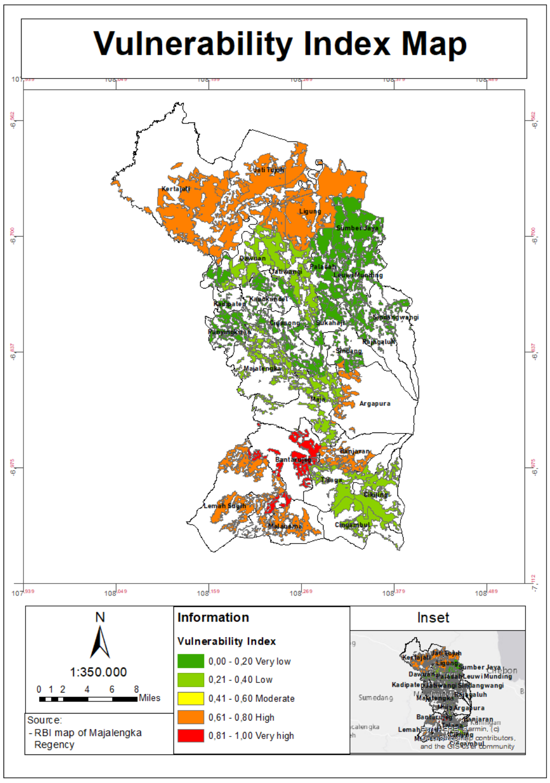

Figure 4. Map of potential vulnerability distribution in Majalengka Regency.

Potential Risk of Decreasing Rice Production in Majalengka Regency. Based on the results of an analysis of the potential risk of decreasing rice production in Majalengka Regency, it is indicated that areas with a very high risk of decreasing rice production are in Kertajati District with an index of 1.00. This shows that the Kertajati area has the highest level of hazard and vulnerability to decreased rice production among other regions, because it has a potential hazard index of 1.00 while vulnerability is in the high category with an index of 0.68.

Bantarujeg and Ligung sub-districts are included in the areas with a high level of risk with an index of 0.62 and 0.8. The moderate risk index area is located in Lemahsugih and Jatitujuh sub-districts with indexes of 0.49 and 0.55. At the same time, other regions are dominated by low to very low-risk levels of production decline. The distribution of potential levels of risk of decreasing rice production in Majalengka Regency is also mapped spatially as shown in Figur.

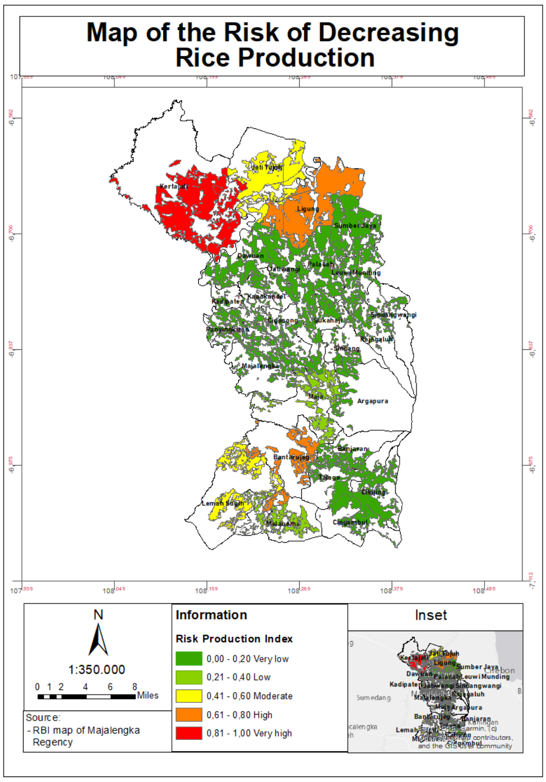

Figure 5. Map of distribution of potential production decline risks

Potential Risk of Decreasing Rice Productivity in Majalengka Regency. Analysis of the potential risk of decreased productivity is calculated per unit area of land planted with rice (ha), based on these results it can be seen that the most at-risk area (very high) is in Bantarujeg District with an index of 1.00. This shows that Bantarujeg District has the highest level of hazard (potential for yield reduction due to weather changes) and vulnerability (farmers' socio-economic conditions) which are the highest among other regions. Areas with a high level of potential risk are in six sub-districts including Lemahsugih, Malausma, Argapura, Kertajati, Jatitujuh and Ligung with an index of 0.62-0.71. Meanwhile, other areas in Majalengka Regency are dominated by the low to very low category with an index of 0.06-0.36. The distribution of potential risk levels for decreasing rice productivity in the Majalengka Regency area is shown in Figure 6.

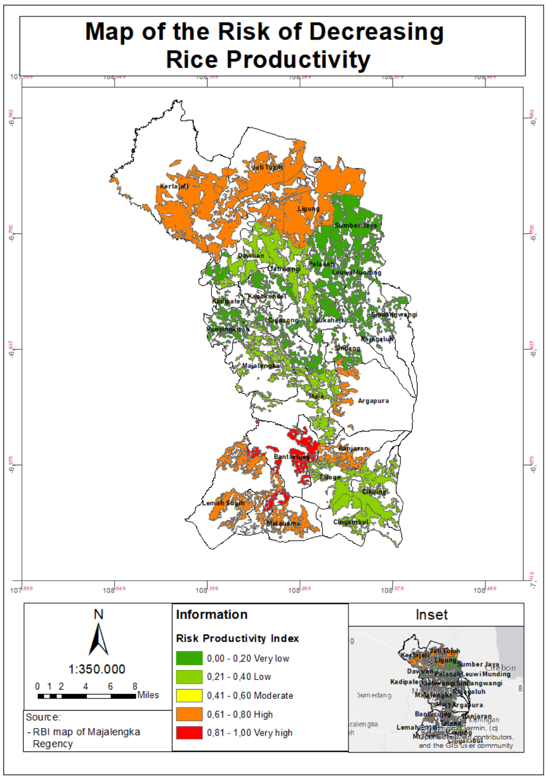

Figure 6. Map of distribution of potential levels of risk of decreasing productivity

Conclusion

Based on the results of the research that has been done, several conclusions can be drawn including:

1. Majalengka Regency is experiencing climate change which is marked by an increase in average air temperature of 0.33^{o}C and decreased rainfall by 56.4 mm, as well as the addition of consecutive dry months in the period 2006-1990.
2. An increase in average air temperature of 0.33^{o}C with a decrease in rainfall of 56.4 mm in Majalengka Regency has the potential to reduce production by 6% and rice productivity by 8%.
3. Areas that have the potential to have a level of hazard, vulnerability and risk of decreased rice production and productivity include:
   - Areas with a very high potential danger of decreasing rice production are in Kertajati District; high level is located in the districts of Jatitujuh and Ligung. Meanwhile, all sub-districts in Majalengka Regency have a very high potential to reduce rice productivity.

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- Areas with very high vulnerability potential are in Bantarujeg District. Meanwhile, several sub-districts in Majalengka Regency are at a high level of vulnerability.
- Areas with a very high potential risk of decreasing rice production are in Kertajati District; the risk level of rice production in the high category is in Bantarujeg and Ligung Districts. Meanwhile, areas with a very high level of potential risk of decreasing rice productivity are in Bantarujeg District and several sub-districts that have a high level of productivity risk.

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