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Mapping Risk of Changes in Rainfall Pattern And Mitigation Strategies Rice Production Using Spatial Data in East Java, Indonesia

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Rainfall Pattern; Mitigation; Rice Productivity; Climate Change, Spatial Data

Abstract
Climate change is a global challenge that has a significant impact on the sustainability of agricultural systems and global food security. Rice productivity in East Java Province in 2024 experienced a decline of 4.78% due to prolonged drought/El Nino and climate anomalies as the main causes of production decline in several districts due to shifts in planting times (planting seasons) and crop failures. Unpredictable climate fluctuations can reduce land productivity, shorten the planting period, and threaten food price stability at the consumer level. The objective of this study was to identify the risk mapping of changes in rainfall patterns and mitigation strategies for rice productivity in East Java. The results show that, overall, rainfall in various regions in East Java does not have a significant effect ($P > 0.05$) on rice productivity, while spatial data-based mitigation results show that the overlay map of drought and flood risks is in the districts of Jember, Tuban, Lamongan, Bojonegoro, and Ngawi, with medium to high drought risk categories and high flood risk categories. For landslide risk zones, it was found that parts of Jember were included in the relatively high landslide risk category.

Kata Kunci:
Pola Curah Hujan; Mitigasi; Produktivitas Padi, Perubahan Iklim, Data Spasial

Abstract
Perubahan iklim merupakan tantangan global yang berdampak signifikan terhadap keberlanjutan sistem pertanian dan ketahanan pangan dunia. Produktivitas Padi di Provinsi Jawa Timur pada tahun 2024 mengalami penurunan sebesar 4,78% diakibatkan kemarau panjang/El Nino dan anomali iklim sebagai penyebab utama penurunan produksi di beberapa kabupaten akibat terjadinya pergeseran waktu tanam (musim tanam) dan kegagalan panen. Fluktuasi iklim yang tidak menentu dapat menurunkan produktivitas lahan, memperpendek masa tanam, serta mengancam stabilitas harga pangan di tingkat konsumen. Tujuan penelitian adalah untuk mengidentifikasi pemetaan risiko perubahan pola curah hujan dan strategi mitigasi terhadap produktivitas tanaman padi di Jawa Timur. Hasil penelitian menunjukkan bahwa secara keseluruhan curah hujan di berbagai wilayah di Jawa Timur tidak menunjukkan pengaruh nyata ($P > 0,05$) terhadap produktivitas padi, sedangkan hasil mitigasi berbasis data spasial menunjukkan peta overlay risiko kekeringan dan risiko banjir berada di kabupaten Jember, Tuban, Lamongan, Bojonegoro, dan Ngawi dengan kondisi kategori risiko kekeringan medium hingga tinggi sedangkan risiko kebanjiran berada pada kategori tinggi. Untuk zona risiko longsor memperlihatkan bahwa sebagian wilayah Jember termasuj dalam kategori risiko longsor yang relatif tinggi.

INTRODUCTION

Climate change is a global challenge that has a significant impact on the sustainability of agricultural systems and global food security. This phenomenon is characterized by an increase in the average temperature of the earth, shifts in rainfall patterns, and an increase in the frequency of extreme weather events such as droughts and floods (Duchenne-Moutien & Neetoo, 2021). Climate change will have a direct impact on agriculture because this sector is highly sensitive to climate variability (Dar et al., 2023). Factors such as rising average temperatures, changes in rainfall patterns, and an increase in extreme weather events (floods, droughts) directly affect critical phases of plant growth (such as flowering and pollination), irrigation water availability, and pest/disease outbreaks (Khan et al., 2023; Thornton et al., 2022). Climate change, defined by the United Nations Framework Convention on Climate Change (UNFCCC), is a change caused either directly or indirectly by human activities that alters the composition of the global atmosphere and natural climate variability over a comparable time period. The global atmospheric composition referred to is the composition of the Earth's atmospheric materials in the form of greenhouse gases (GHGs), which include carbon dioxide, methane, nitrogen, and so on. Basically, greenhouse gases are necessary to maintain the Earth's temperature stability. East Java Province is known as one of the national food barns with a significant contribution to Indonesia's food security. The advantage of this region lies in its diverse agroclimatic conditions, ranging from lowlands to mountains, which allow various types of agricultural commodities to grow well. Therefore, the agricultural sector in East Java has a strategic position, both in the provision of food, industrial raw materials, and as a pillar of the rural economy. In the food crop subsector, rice is one of the main strategic commodities in supporting regional food security.

Climate change has a significant impact on the agricultural sector, which directly threatens food security. This sector is highly vulnerable to climate fluctuations because they affect planting patterns, planting schedules, production quantities, and crop quality. Agricultural production is influenced by climate change variables such as rising temperatures, changes in rainfall, evaporation of water runoff, and soil moisture, which affect productivity (Hidayat, et al, 2019). The impact of climate change is particularly noticeable in rice crops. Unpredictable climate fluctuations can reduce land productivity, shorten the planting period, and threaten food price stability at the consumer level (Abidin, 2024). The risks of climate change are also exacerbated by local agroclimatic conditions and farming practices that are currently still vulnerable to abiotic stress (drought, flooding) and attacks by plant pests (Mariyanto, 2025). For example, increased fluctuations in temperature and humidity can trigger outbreaks of pests and diseases that damage crops (Pribadi and Anggraeni, 2010).

Rice productivity in East Java declined in 2024 compared to 2023. The rice harvest area in 2024 reached 1.62 million hectares, a decrease of 0.08 million hectares or 4.78 percent compared to the rice harvest area in 2023, which was 1.70 million hectares. Rice production in 2024 was 9.27 million tons of GKG, a decrease of 0.44 million tons or 4.53 percent compared to rice production in 2023, which was 9.71 million tons of GKG. Rice production in 2024 for public consumption reached 5.35 million tons, a decrease of 0.25 million tons or 4.53 percent compared to rice production in 2023, which was 5.61 million tons (BPS Jatim, 2025). Based on regional reports, the main causes of the decline in production in several districts were the prolonged drought/El Nino and weather anomalies, which led to shifts in planting times (planting seasons) and crop failures.

Recent developments have shown natural phenomena that indicate changes in natural behavior, leading to unusual patterns. A few years ago, farmers could still predict when the dry and rainy seasons would begin and end, allowing them to prepare when to start planting rice and when to harvest it. However, climate change has now made this difficult to predict (Handajani et al., 2023). There is a complex interconnectivity between climate anomalies, food production, and global environmental dynamics, which requires a multidisciplinary approach to address it. This approach must include the integration of agricultural policies, water resource management, and mitigation and adaptation based on scientific data to reduce the vulnerability of the food sector to climate change (Arifin, 2022).

This research has a gap with other research results in that the integration of spatial climate data with strategic commodity production data is still very limited. Whereas previous studies mostly used aggregate climate data for a single district, this study uses climate data at the provincial level so that it can capture climate variations between districts.

METHODS

Experimental Design

This study uses a quantitative approach with linear regression analysis to determine the effect of rainfall on rice productivity from 2015 to 2025. In this study, rainfall data is adjusted to the usual planting periods, namely January, February, March, November, and December. This time frame reflects the critical phases of rice from planting to early vegetative growth. Then, a spatial data-based strategic commodity analysis was conducted by classifying rainfall using BMKG standard categories consisting of very low (<100 mm/month); low (100-150 mm/month); medium (150-300 mm/month); High (300-500 mm/month) and very high (>500 mm/month). Commodity production data was then grouped into three categories high (in the 75–100% quartile), medium (25–75% quartile), and low (0–25% quartile) to produce a production map layer for each commodity. Spatial analysis was then conducted by overlaying rainfall and production data to identify spatial relationships, including areas with high production at optimal rainfall, areas with low production due to extreme rainfall, and relatively stable areas. An additional overlay with disaster risk maps was used to identify productive areas prone to disasters and areas with the potential for reduced production due to drought or flooding, as well as to determine intervention priorities.

Regresion Analysis

Research variables:
Independent variable (X): Rainfall (mm/month)
Dependent variable (Y): Commodity productivity (tons/ha)
The simple formula used is:

$$\boldsymbol{Yi = \beta 0 + \beta 1 Xi + \epsilon i}$$

Explanation:
Yi = commodity productivity (tons/ha)
Xi = rainfall (mm/year)

$\beta 0$ = intercept
$\beta 1$ = rainfall influence coefficient
ϵi = error
In hypothesis testing, the conditions are:
If p-value < 0.05 → Reject H0 → This means there is a significant influence (a real effect).
If p-value > 0.05 → Fail to reject H0 → Meaning there is no significant effect (no real effect)

Using the overlay technique between the BMKG standard rainfall classification map and the rice crop production category map, this integration identifies the spatial relationship between weather anomalies and crop yield declines.

RESULTS AND DISCUSSION

The Effect of Rainfall on Rice Production in East Java

The regression analysis results show that rainfall has no significant effect (P>0.05) on rice production. The regression results are presented in Table 1.

Table 1. Results of Rainfall and Rice Production Regression Analysis

Kota/Kabupaten	Multiple R	R Square	Significance F	Persamaan regresi
Pacitan	0,27	0,07	0,44	Y= 112432,11 - 54,87 x
Ponorogo	0,08	0,01	0,83	Y= 371157,80 + 71,65 x
Trenggalek	0,36	0,13	0,31	Y= 52887,59 + 269,27 x
Tulungagung	0,16	0,03	0,66	Y= 262378,70 - 89,22 x
Blitar	0,18	0,03	0,62	Y = 175984,44 + 174,32 x
Kediri	0,75	0,57	0,01	Y= 95416,43 + 496,97 x
Malang	0,00	0,00	1,00	Y= 300943,57 + 1,98 x
Lumajang	0,03	0,00	0,93	Y= 331872,95 -32,32 x
Jember	0,05	0,00	0,90	Y= 732601,49 -123,63 x
Banyuwangi	0,02	0,00	0,96	Y= 510752,09 + 51,91 x
Bondowoso	0,01	0,00	0,98	Y= 286231,83 -9,53 x
Situbondo	0,25	0,06	0,48	Y= 249064,84 -257,37 x
Probolinggo	0,14	0,02	0,70	Y= 238849,12 -104,41 x
Pasuruan	0,19	0,04	0,60	Y= 183636,31 + 561,44 x
Sidoarjo	0,29	0,08	0,42	Y= 249526,92 -146,44 x
Mojokerto	0,06	0,00	0,88	Y= 319747,52 -24,46 x
Jombang	0,01	0,00	0,97	Y= 373506,12 + 19,20 x
Nganjuk	0,51	0,26	0,13	Y= 272004,65 + 538,00 x
Madiun	0,24	0,06	0,51	Y= 387828,74 + 200,43 x
Magetan	0,60	0,36	0,07	Y= 184242,41 + 370,64 x
Ngawi	0,15	0,02	0,68	Y= 755135,89 + 78,46 x
Bojonegoro	0,19	0,04	0,60	Y= 841333,09 -324,05 x
Tuban	0,16	0,03	0,66	Y= 574510,47 -181,46 x
Lamongan	0,18	0,03	0,62	Y= 914269,70 -214,14 x
Gresik	0,02	0,00	0,96	Y= 386567,12 + 15,01 x
Bangkalan	0,34	0,11	0,34	Y= 300622,50 -299,54 x
Sampang	0,26	0,07	0,46	Y= 147171,35 + 116,25 x

Pamekasan	0,45	0,20	0,19	Y= 99287,31 + 23,19 x
Sumenep	0,45	0,20	0,20	Y= 141134,66 + 307,43 x
Kota Kediri	0,29	0,08	0,42	Y= 6236,3 + 8,59 x
Kota Blitar	0,04	0,00	0,92	Y= 5504,73 + 0,60 x
Kota Malang	0,06	0,00	0,86	Y= 12266,35 -1,69 x
Kota Probolinggo	0,62	0,38	0,06	Y= 3786,93 + 21,98 x
Kota Pasuruan	0,65	0,43	0,04	Y= 4108,95 + 49,11 x
Kota Mojokerto	0,24	0,06	0,51	Y= 3415,24 + 2,66 x
Kota Madiun	0,39	0,15	0,27	Y= 7366,72 + 15,20 x
Kota Surabaya	0,52	0,27	0,12	Y= 4903,34 + 15,64 x
Kota Batu	0,30	0,09	0,41	Y= 6825,11 -7,68 x

Based on the results in Table 1, overall rainfall in various regions in East Java did not show a significant effect (P> 0.05) on rice productivity. This finding contradicts a number of previous studies that reported a significant relationship between rainfall (or climate variability) and rice yields, as reported by (Andrista et al., 2025). However, field observations show that farmers have demonstrated sensitivity in determining the planting season based on the onset of rainfall. Based on this practice, the most significant effect of rainfall is not the quantity of rainfall itself, but rather the variability and uncertainty in planting time, namely the length of the interval (space) between the end of the rainy season and the next planting time (Wijaya, 2023). This is reflected in the decline in food production in a number of commodities, such as rice, soybeans, and sugar cane, as shown in Figure 1.

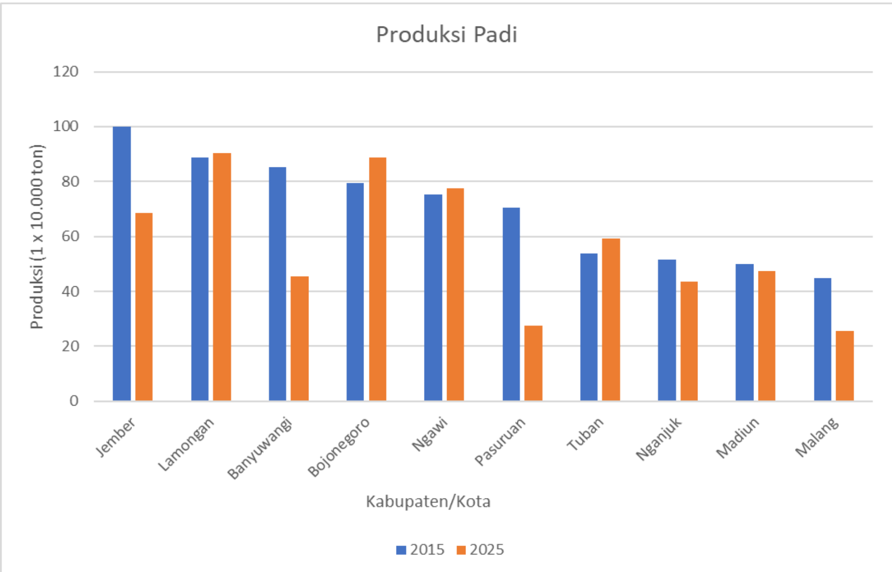

Figure 1. The difference in rice production between 2015 and 2025

Based on Figure 1, it can be seen that the ten districts/cities with the highest rice production in East Java experienced a decline in production in 2025 compared to 2015. This decline is evident in several rice-producing areas such as Jember, Lamongan, Banyuwangi, Bojonegoro, Ngawi, Pasuruan, Tuban, Nganjuk, Madiun, and Malang. This decline in production is not isolated, but is influenced by a combination of ecological and technical factors, as well as farmers' strategic decisions in determining planting patterns. One of the main causes of the decline in production is the increasingly long idle period before the next planting season. Farmers deliberately extend the idle period to reduce the risk of crop failure due to high and unpredictable rainfall.

In some areas, increased rainfall intensity has caused flooding, increased the risk of plant diseases, and the potential for damage to seedlings if planted too early. These extreme rainfall conditions have made farmers more cautious, causing them to delay planting until conditions are considered safer. These findings are consistent with reports that changes in rainfall patterns tend to influence planting decisions, the duration of the planting season, and overall crop yields (Arifin, 2020; BMKG, 2022).

In addition, there are indications that some of the rice fields in these districts have been temporarily converted to other commodities. Farmers have started planting shallots, chilies, or corn as alternatives to minimize risk and pursue higher profits during periods of rising horticultural commodity prices. This crop conversion is quite common when farmers see more promising economic opportunities or when agroclimatic conditions are more favorable for crops other than rice. Crop shifts as a form of agricultural adaptation to climate change have also been widely reported in previous studies (Hidayat & Sari, 2019; Yusuf et al., 2021).

Overall, the decline in rice production in the 10 largest districts/cities in East Java during the 2015–2025 period can be seen as a form of responsive adaptation by farmers to climate uncertainty, particularly increased rainfall and the risk of crop failure. This situation confirms that the dynamics of food crop production are greatly influenced by the interaction between climate change, farmers' adaptation behaviors, and market conditions that encourage commodity diversification.

Spatial Data-Based Rice Crop Mitigation (Map Overlay)

Based on Dryness Risk

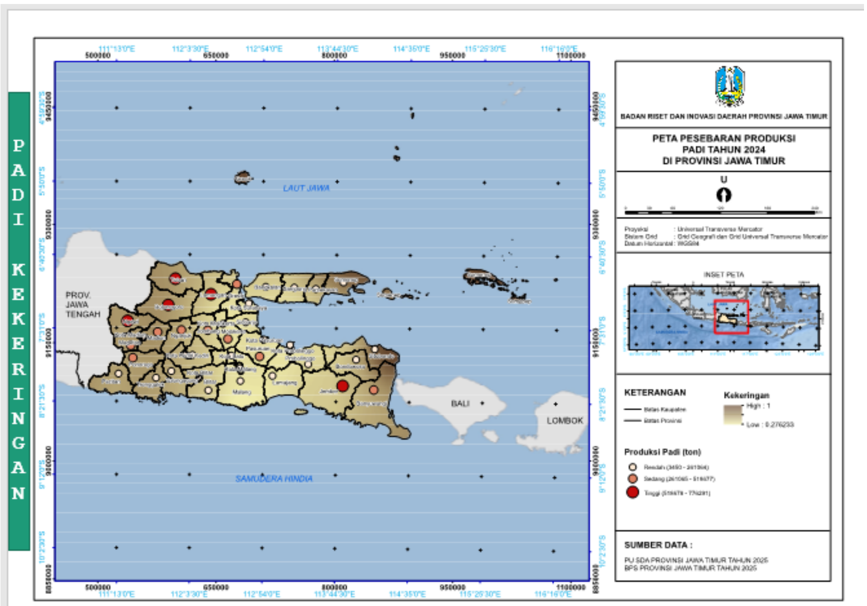

Figure 2. Dryness Risk in Rice Crops

The 2024 rice production distribution map in East Java Province shows that the areas with the highest rice production are in Jember, Tuban, Lamongan, Bojonegoro, and Ngawi Regencies. These five areas have long been known as rice production centers that support the province's food security. However, when overlaid with the drought risk map, most of these areas are in the medium to high drought risk category. This imbalance indicates that the sustainability of rice production in these areas is under serious threat, especially when extreme climate phenomena such as El Niño occur. Northern East Java, including Tuban, Lamongan, and Bojonegoro, is prone to water deficits during long dry seasons. Previous studies show that these areas periodically experience a decline in irrigation water supply, which affects rice productivity, especially when rainfall decreases by 20–30% during the critical phase of plant growth (Widianto et al., 2021). This condition is in line with the BBSDLP (2023) report, which states that East Java is one of the provinces with the highest area of rice fields exposed to drought in Indonesia over the past two years.

The situation on the ground varies greatly depending on water sources and irrigation types. In Tuban, Lamongan, and Bojonegoro, many rice fields depend on technical irrigation from the Bengawan Solo River Basin. During the dry season, river discharge often decreases so that tertiary irrigation channels cannot distribute water evenly. As a result, farmers often delay planting, switch to secondary crops, or use water pumps, which increases production costs by 10–20%. Some areas even experience wide cracks in the soil due to prolonged drought. Meanwhile, the Ngawi region, which is relatively better in terms of irrigation networks, still faces challenges when water discharge is insufficient, so that some farmers also rely on pumps. In Jember, despite relatively wetter agroclimatic conditions, the decline in rainfall still causes water distribution disruptions, especially in highlands and dry fields, thereby affecting rice productivity.

When viewed as a whole, the conditions on the map show that East Java's main food production centers face increasing climate vulnerability. This has the potential to reduce production from year to year, especially when drought intensity increases and adaptation technologies have not been optimally implemented. Research by Yulianingsih and Prasetyo (2020) confirms that climate variability contributes significantly to crop yield fluctuations in East Java, with areas with unstable irrigation being the most vulnerable. Therefore, irrigation optimization, improvement of water distribution networks, application of drought-tolerant rice varieties, and water-saving planting strategies such as Alternate Wetting and Drying are crucial to maintaining production sustainability. Without adequate adaptation measures, production centers that have been the backbone of the province's food security are at risk of declining production and increased risk of crop failure in future extreme seasons.

Based on Flood Risk

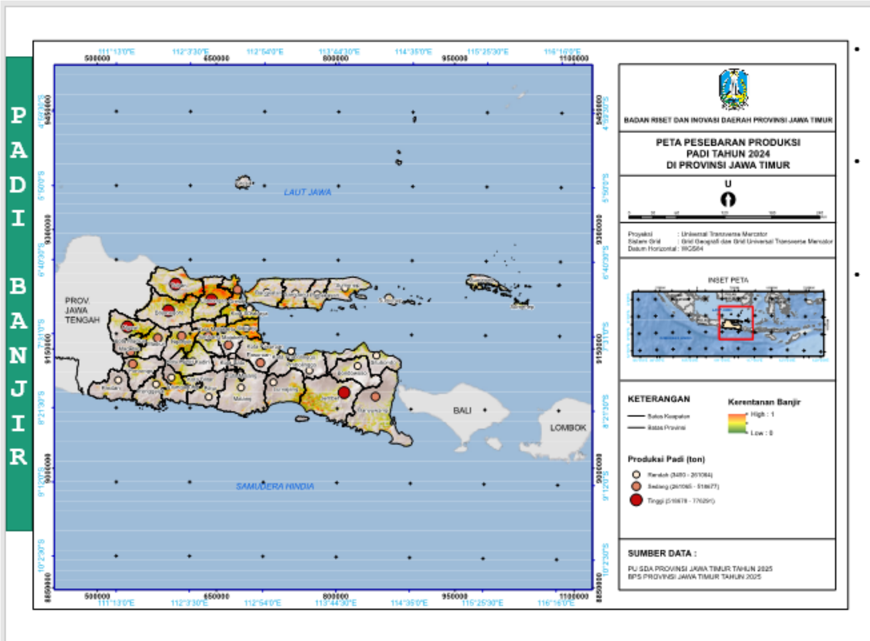

Figure 3. Flood Risk in Rice Crops

The map shows the distribution of rice production in East Java Province in 2024, indicating that the areas with the highest rice production are in Jember, Tuban, Lamongan, Bojonegoro, and Ngawi Regencies. As with the previous drought map, these five areas are major food production centers that have been significant contributors to the province's total rice production. However, when viewed from the flood vulnerability map overlay, these high-production areas are actually located in medium to high flood risk zones. This means that, in addition to facing the threat of drought in the dry season, these rice centers are also potentially experiencing production disruptions due to high incidence of flooding during the rainy season. The imbalance between high production and high risk of hydrometeorological disasters shows that East Java's food security is highly influenced by climate variability and local hydrological conditions. A study by Novitasari and Sutrisno (2022) shows that the northern region of East Java is highly sensitive to fluctuations in river discharge and extreme rainfall, which can cause surface runoff to increase dramatically, making it difficult to avoid flooding in rice fields.

Field conditions in rice-growing centers such as Lamongan, Tuban, and Bojonegoro during the rainy season are generally characterized by high rainfall intensity, causing irrigation channels to overflow. Some low-lying areas experience flooding for 3–7 days, which is sufficient to reduce rice productivity, especially during the vegetative and generative phases. Farmers often report damage to rice plants due to submersion, an increase in plant diseases such as leaf blight and blast, and delays in planting because the land cannot be cultivated. Meanwhile, in Ngawi, the threat of flooding comes mainly from the overflowing of the Bengawan Solo River when its discharge increases at the peak of the rainy season, making land in the basin more vulnerable. In the Jember region, flash floods originating from upstream areas and mountain slopes also have the potential to deposit sediment into rice fields, disrupt soil structure, and damage irrigation networks. These conditions are in line with the findings of BBSDLP (2023) that most of the productive rice fields in East Java are located near large rivers or main irrigation channels that are prone to overflowing when rainfall increases sharply.

This flooding phenomenon poses a serious threat, given that rice is a commodity that is highly sensitive to hydrometeorological pressures. Rice plants can tolerate light flooding, but flooding of more than 50 cm for several days can reduce production by 30–70% (Widianto et al., 2021). The conditions shown on the map indicate that the food production centers that have been the backbone of East Java's food security are now facing the risk of multiple disasters: drought in the dry season and flooding in the rainy season, both of which have a negative impact on productivity. Global climate variability, such as La Niña and extreme weather anomalies, has the potential to exacerbate the frequency and intensity of flooding. The impact is not only on reduced production, but also on increased farming costs, damage to irrigation infrastructure, and disruption to planting patterns. This situation underscores the need for mitigation strategies such as drainage network rehabilitation, development of early flood warning systems, increased drainage capacity, and the use of flood-tolerant rice varieties as efforts to adapt to climate change in the food sector.

Based on Landslide Risk

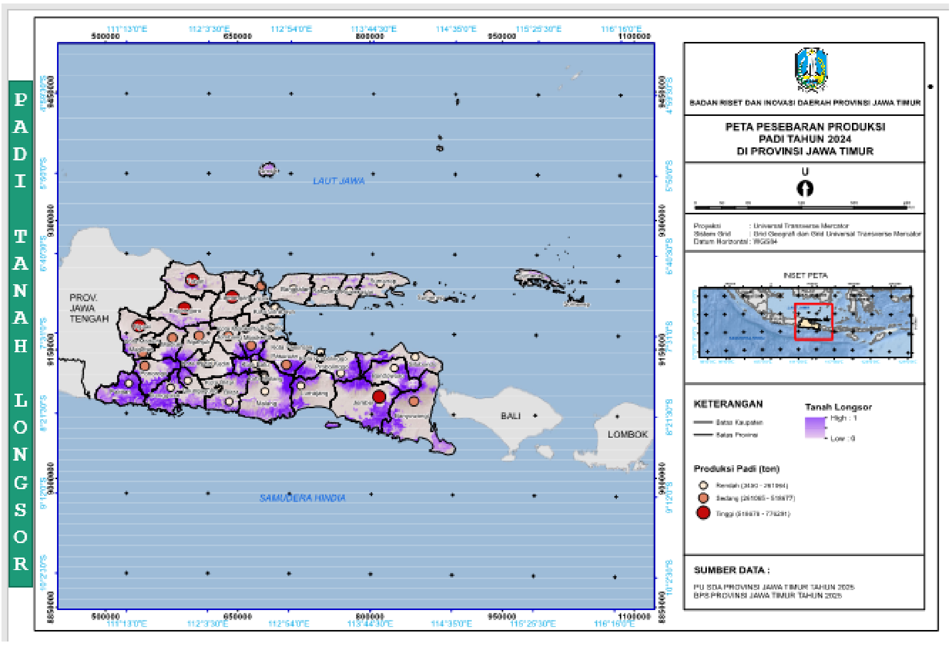

Figure 4. Landslide Risk in Rice Crops

The 2024 rice production distribution map in East Java Province shows that the region with the highest rice production is in Jember Regency. However, the landslide risk map shows that parts of Jember are included in the relatively high landslide risk zone. Nevertheless, this condition does not necessarily threaten rice production directly, because rice cultivation in Jember is generally carried out on flat land in valleys or alluvial plains that have good water availability and are not located on steep slopes. The high-risk zones for landslides in Jember are mostly located in hilly areas and mountain slopes, especially in Silo, Arjasa, and Panti subdistricts, which are upstream areas with soil characteristics that are easily saturated with water and have high erosion rates. These areas are not center of rice cultivation, so the threat of landslides does not interfere with main production in the rice fields.

Field conditions show that landslides have had a greater impact on accessibility and agricultural support infrastructure than on rice fields themselves. Several landslide incidents in Jember in recent years have more often blocked farm roads, damaged secondary irrigation channels, or cut off access to transport crops, especially in areas close to slopes (BBSDLP, 2023). These indirect impacts can cause delays in the distribution of fertilizers, seeds, or crops, thereby affecting production efficiency. In lowland areas, rice farmers are relatively safe from the threat of landslides, but they still feel the impact when extreme rains cause runoff from the hills to carry sediment into irrigation channels. This accumulation of sediment can reduce the water flow into rice fields, making irrigation management more difficult during the rainy season.

However, the threat of landslides should not be ignored, given the increasing trend of extreme rainfall intensity due to climate change. Research by Yulianingsih and Prasetyo (2020) notes that East Java has experienced an increase in the frequency of short but intense rainfall, which increases the likelihood of landslides in hilly areas. Major landslides can cause damage to upstream ecosystems, disrupt watershed stability, and ultimately impact irrigation systems in downstream areas that are rice production centers. In addition, increased land clearing on slopes and reduced vegetation cover also exacerbate landslide vulnerability. Therefore, mitigation efforts such as planting conservation vegetation, strengthening terraces, and improving drainage systems in landslide-prone areas are essential to ensure the sustainability of rice production, even if the rice fields are not located directly in the risk zone.

CONCLUSION

Based on the results of the study, it can be concluded that the risk of changes in rainfall patterns in East Java does not show a statistically significant direct impact on rice productivity in all districts ($P>0.05$). Further results show that there is adaptive behavior among farmers, particularly in adjusting the planting calendar and crop diversification strategies in response to rainfall uncertainty. In addition, spatial risk mapping (overlay maps) reveals that the districts with the highest rice production, namely Jember, Tuban, Lamongan, Bojonegoro, and Ngawi, are simultaneously exposed to moderate to high risks of drought and flooding. The risk of landslides, although relatively high in some areas of East Java, particularly in the hilly areas of Jember, does not directly impact rice production zones, most of which are located in lowland areas.

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