Assessment of the 2015 and 2019 Droughts in the Rice Agriculture Sector in Java

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ABSTRACT

Drought is a natural phenomenon that occurs due to low rainfall. Drought has a slow onset character, but its effects are far-reaching. With climate change, drought events are increasing in frequency and intensity. Drought in Indonesia is related to the natural phenomena of El Niño-Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD). Agriculture is the sector most affected by the drought. Drought can damage food crops and ultimately threaten food security. In the last decade, there have been two severe droughts, namely in 2015 and 2019. This study aimed to assess the impact of the droughts in 2015 and 2019 on rice agriculture in Java, Indonesia's main food barn. The Standardized Precipitation Evaporation Index expresses the dryness level with a time-scale of 3 months (SPEI-3) and 6 months (SPEI-6). The level of the drought was mapped to see its spatial distribution using the gaussian krigging interpolation method. The impact of drought is expressed in the area of agricultural rice land affected by drought by province. The evaluation results show that the 2015 drought had the lowest SPEI-3 value of -2.06 in September 2015, and the lowest SPEI-6 value of -1.52 occurred in January 2016. The rice agriculture land affected by drought throughout 2015 was around 246 thousand hectares. The 2019 drought lasted longer because it started in the middle of 2018. The lowest SPEI-3 value of -2.06 occurred in August 2019, and the lowest SPEI-6 value of -1.96 occurred in October 2019. The drought impacted around 120 thousand and 223 thousand hectares of rice land in 2018 and 2019, respectively. The results of the SPEI value mapping indicate that the eastern part of Java Island is experiencing a more severe drought than the western part. However, the impact of the drought on rice agriculture is more significant in the west. It indicated that the western part of Java Island is an area that is prone to drought, while the eastern part is more resilient to drought disasters.

Keywords: *Drought, Food security, Hydrometeorological disasters, SPEI.*

1. INTRODUCTION

Hydrometeorological disasters, such as floods, droughts, and landslides, are the most frequent disasters in Indonesia [1]. Drought is a natural phenomenon that occurs due to low rainfall. Drought has a slow onset character, so it is difficult to determine the start and the end of drought events. Nevertheless, drought disasters usually cover a huge area. With climate change, drought events are increasing in frequency and intensity. Drought in Indonesia is related to the natural phenomena of El Niño-Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) [2]. The severity of the drought was shown to be reliant on the intensity of El Niño and a positive-phase IOD that occurred concurrently, whereas the length appears to be influenced more by the positive-phase IOD.

Agriculture is the most affected sector by the drought. When drought occurs, the water in the soil is insufficient to meet plants' water needs, so plants cannot grow properly. If it happens for a long time, it can cause crop failure. Despite being home to 57 percent of Indonesia's population and producing more than 55 percent of the nation's rice [3, 4], Java Island contains less than 10 percent of all available water and land resources in Indonesia. When drought occurs in Java, national water and food security can be threatened. Data from 2014 to 2018 in Central Java reveal that the link between yearly rainfall and the drought-affected area is greater than the

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correlation between rainfall and the flood-affected area [5]. The El Nino and a positive-phase Indian Ocean Dipole (IOD) altered meteorological droughts in the eight main rice-producing regions in Java [6].

Standardized Precipitation Index (SPI) and Standardized Precipitation and Evapotranspiration Index (SPEI), with their various time-scale, are drought indices that are commonly used. SPI only uses precipitation as its input. Meanwhile, based on temperature and precipitation data, the SPEI has the benefit of integrating multiscalar properties to consider temperature variability when determining drought severity [7]. Recent research on Java Island [8] discovered that, in contrast to the SPEI, the SPI predicted drought severity with an abnormally high estimate. Another study also found that satellite-based precipitation monitoring demonstrates the possibility of anticipating meteorological drought conditions in Java and mitigating their impacts several months in advance [6].

A prior study found connections between the drought index with the impacted rice crops [9]. That study employed ground-based precipitation data from 1980 to 2010 as the input to calculate the SPI-3 value as a drought indicator. In the last decade, nevertheless, there have been two severe droughts occurred in 2015 and 2019. Therefore, more recent research is needed to evaluate the impact of drought on rice agriculture, especially in 2015 and 2019. The objective of this study was to assess the impact of the droughts that occurred in 2015 and 2019 on rice agriculture in Java, Indonesia's main food barn. By evaluating past events, future drought management hopefully could be done better, and the impact of the drought could be minimized. In this study, we used the satellite-based seasonal SPEI with a time scale of 3 months and 6 months (SPEI-3 and SPEI-6) as the indicator of drought.

2. METHODS

2.1. Study Area

The study area is Java Island which has an area of 128,297 km^2 and a population of 151.6 million people in 2020. Java Island is located in the southern part of the equator with coordinates 113° 48′ 10″ - 113° 48′ 26″ E and 7° 50′ 10″ - 7° 56′ 41″ S. Administratively, Java Island is divided into 6 provincial regions (Figure 1): Banten, Special Capital Region of Jakarta, West Java, Central Java, Special Region of Yogyakarta, and East Java.

2.2. Data Collection

SPEI values are obtained from the SPEI Global Drought Monitor [10]. The SPEI Global Drought Monitor uses NOAA NCEP CPC GHCN_CAMS gridded dataset to derive mean temperature data. Data for monthly precipitation amounts are derived from satellite-based precipitation Global Precipitation Climatology Centre (GPCC) best estimation. Data with a resolution of 0.5° is interpolated to a resolution of 1°. The Thortnthwaite equation is employed to calculate potential evapotranspiration. Drought severity is then classified according to World Meteorological Organization [11], as shown in Table 1.

Data on rice fields area affected by drought from 1997 to 2021 was downloaded from the official website of the Ministry of Agriculture, the Republic of Indonesia [12]. The data on the affected rice field area is monthly data for provinces in Indonesia.

Figure 1 Java Island administration map.

Table 1 Classification of negative SPEI value (modified after WMO No-1090 [11])

Value	Dryness Level	Probability	
0.00 > SPEI > –0.99	Mild dryness	34.1%	1 in 3 years
–1.00 > SPEI > –1.49	Moderate dryness	9.2%	1 in 10 years
–1.50 > SPEI > –1.99	Severe dryness	4.4%	1 in 20 years
SPEI < –2.00	Extreme dryness	2.3%	1 in 50 years

2.3. Data Analysis

SPEI from all grids that intersect with Java Island is averaged, and then the average value is displayed from year to year. Positive values of SPEI mean wet conditions, while negative values mean dry conditions. The values of SPEI-3 and SPEI-6 in the driest months are then mapped to see their spatial distribution. As approaches for spatial evaluation, geostatistical interpolation techniques ordinary kriging Gaussian were used. Previous studies [13, 14] have found that the performance of the ordinary kriging method for interpolating drought indices is better than other spatial interpolation methods. Spatial interpolations were performed using ArcGIS software. Following interpolation, the proportion of dryness level in each province is calculated as a percentage of the total area.

3. RESULTS AND DISCUSSION

3.1 Temporal patterns of SPEI-3 and SPEI-6 and the drought-affected area

The 30-year data series (1991-2020) for the average values of SPEI-3 and SPEI-6 in Java are respectively presented in Figure 2 and Figure 3. There was a tendency for meteorological drought to increase in severity and frequency. The SPEI-3 value with the extreme dry classification (SPEI < -2) only occurred in the last decade, namely 2015 and 2019. Theoretically, extreme dryness conditions have an average of 2.3% probability of occurrence or once in 50 years. In fact, extreme events had repeated themselves in less than five years. The value of SPEI-6 was no more negative than SPEI-3. For SPEI-6, no extreme dry events were recorded during 1991-2020. The most negative SPEI-6 value occurred in 2019. Meanwhile, the SPEI-6 value in 2015 was no more negative than in 2007.

Dry events with moderate to extreme levels are always followed by a significant increase in paddy fields affected by drought, for example, in 1997, 2003, 2007, 2015, and 2019 (see Figure 4). The impact of drought on paddy fields in the last decade (2011-2020) was not as severe as the impact of drought in the previous decade (2001-2010). For example, although the meteorological drought in 2019 was longer and more severe than in 2007, the area of rice fields affected by drought in 2007 was much larger than in 2019. It indicated that drought resilience has increased in Java, especially in the agricultural sector.

Farmers in Java traditionally use their local knowledge to manage disaster risk reduction, such as forecasting climate change using *pranata-mangsa*. It is backed by the relevant stakeholders, who are gradually increasing their support with sophisticated sciences [15]. The issuance of Law no. 24 of 2007 on Disaster Management, the establishment of the National Disaster Management Authority (BNPB) in 2008, followed by the launching of the National Action Plan for Climate Change Adaptation in 2014, may have contributed significantly to drought disaster management. The development of science and technology has also produced new rice varieties that are more resistant to drought. In addition, the drought early warning system has also become more advanced, and the dissemination of drought information has become faster and wider. The government also continues to strive to increase resilience to drought by building infrastructure. In the National Medium-Term Development Plan (RPJMN) 2020-2024 [16], it is planned that 11 new reservoirs will be built in Java to increase water storage in the dry season. In addition, a rehabilitation and modernization program for irrigation networks was also introduced to increase water productivity.

The further evaluation shows that the 2015 drought had the lowest SPEI-3 value of -2.06 in September 2015. It means that the driest 3-months lasted from July-September 2015. The lowest SPEI-6 value of -1.52 occurred in January 2016. It means that the driest 6-months last from August 2015-January 2016. The total area of rice agriculture land affected by drought throughout 2015 was around 246 thousand hectares. The 2019 drought lasted longer because it started in the middle of 2018. The lowest SPEI-3 value of -2.06 occurred in August 2019, and the lowest SPEI-6 value of -1.96 occurred in October 2019. The drought impacted around 120 thousand and 223 thousand hectares of rice land in 2018 and 2019, respectively.

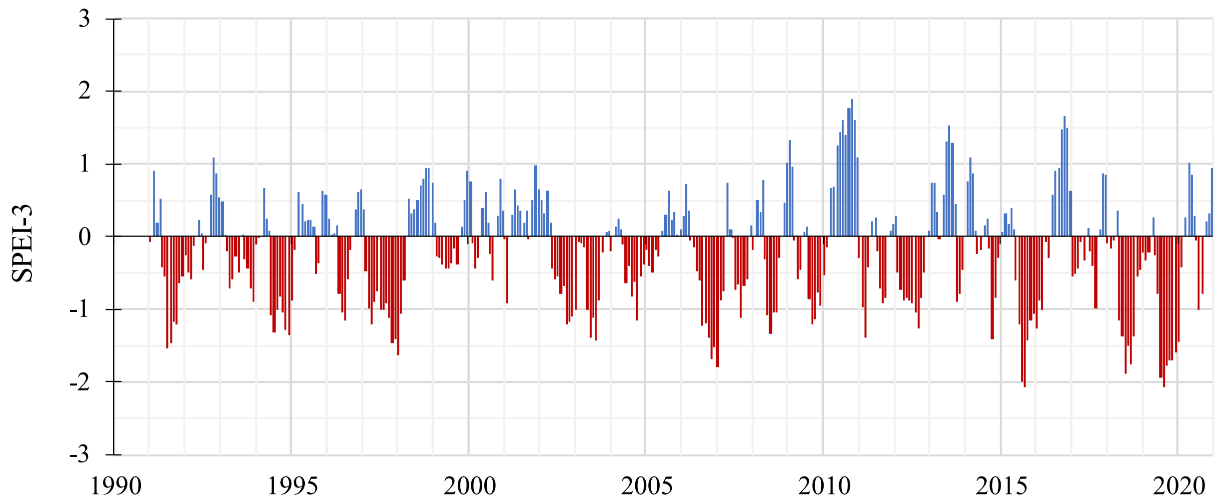

Figure 2 Plot of average SPEI-3 values over Java. The red and blue areas indicate negative values (dry condition) and positive values (wet condition), respectively.

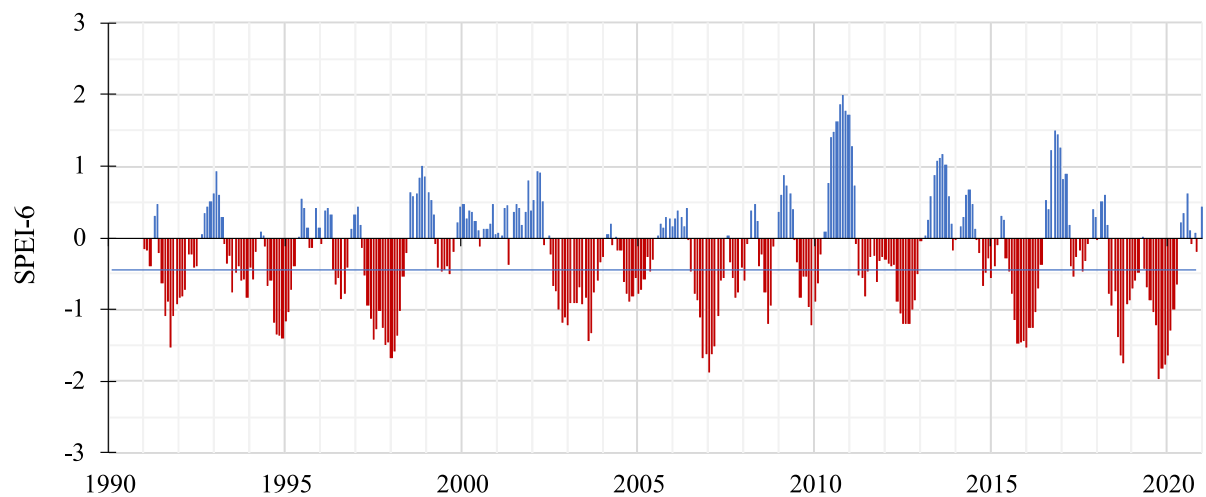

Figure 3 Plot of average SPEI-6 values over Java. The red and blue areas indicate negative values (dry condition) and positive values (wet condition), respectively.

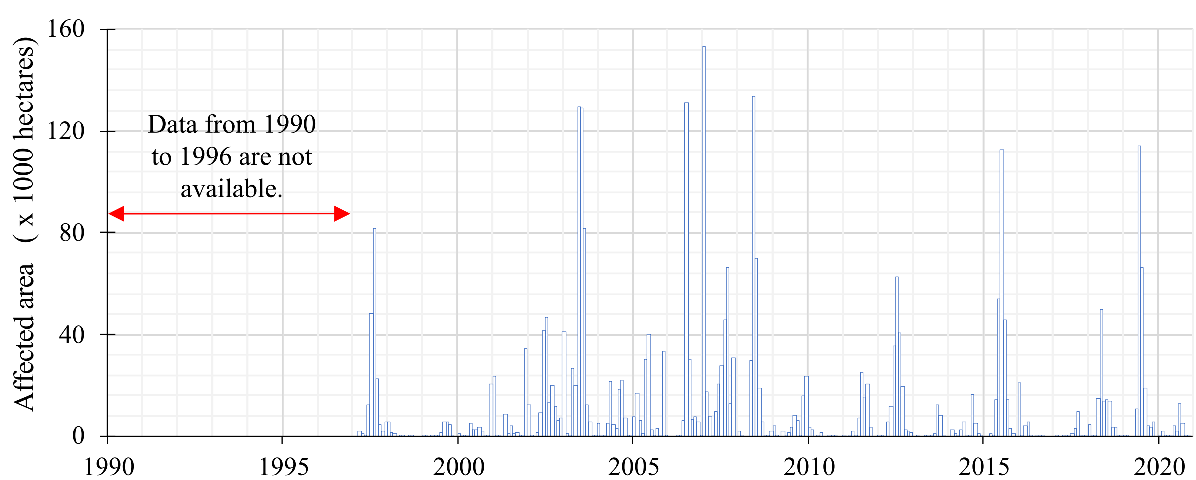

Figure 4 Plot of the area of rice fields on Java Island affected by drought.

3.2 Spatial analysis of drought in 2015 and 2019 and the area of affected rice fields

The distribution of drought levels in Java in the driest months in 2015 and 2019 can be seen in Figure 5 and Figure 6. The driest months were September 2015 and August 2019 for SPEI-3, and January 2016 and October 2019 for SPEI-6. Based on the results of the mapping, it appears that, in general, the eastern part of Java experiences a more severe meteorological drought than the western part of Java. In 2015, almost all central and east Java areas experienced meteorological drought from moderate to extreme levels for both SPEI-3 and SPEI-6, while regions in the western part of Java only experienced mild dryness. The same thing applied to SPEI-6 in October 2019. SPEI-3 showed a slightly different distribution pattern in August 2019. The driest area is on the north coast of central Java. However, the western region remains the region with the mildest drought.

Table 2 shows the area of rice fields affected by drought in each province in 2015 and 2019. The Province of the Special Capital Region of Jakarta is not included in the table because the area of rice fields in the province is very few, so we can ignore it. In 2015, the provinces that experienced the most significant drought impact were West Java and Banten, although the drought index was only at a mild level. The areas affected by drought in West Java and Banten are 14.1% and 12.7% of the total paddy fields in each province. In 2019, the percentage of paddy fields affected by drought in West Java decreased significantly to 7.7%, while in Banten, it was relatively unchanged at around 12.2%. It seems that the rehabilitation program for the Citarum River, the main river in West Java, which was initiated in 2018, is one of the positive influences in increasing drought resilience in West Java. Despite experiencing the most severe meteorological drought, East Java Province did not experience a significant drought impact. Damage to rice fields due to drought in 2015 and 2019 was less than 5%, respectively. In Central Java, the percentage of areas affected by drought did not change much, namely 7.5% in 2015 and 7.2% in 2019. The most significant increase in the percentage of areas affected by drought occurred in DI Yogyakarta, from 0.8% in 2015 to 14.4% in 2019. Prior research [9] also revealed that West Java province was the most susceptible to drought's severe impact on rice paddy crops, while East Java was the most resilient area to drought in 1991, 1994, 2002, and 2004

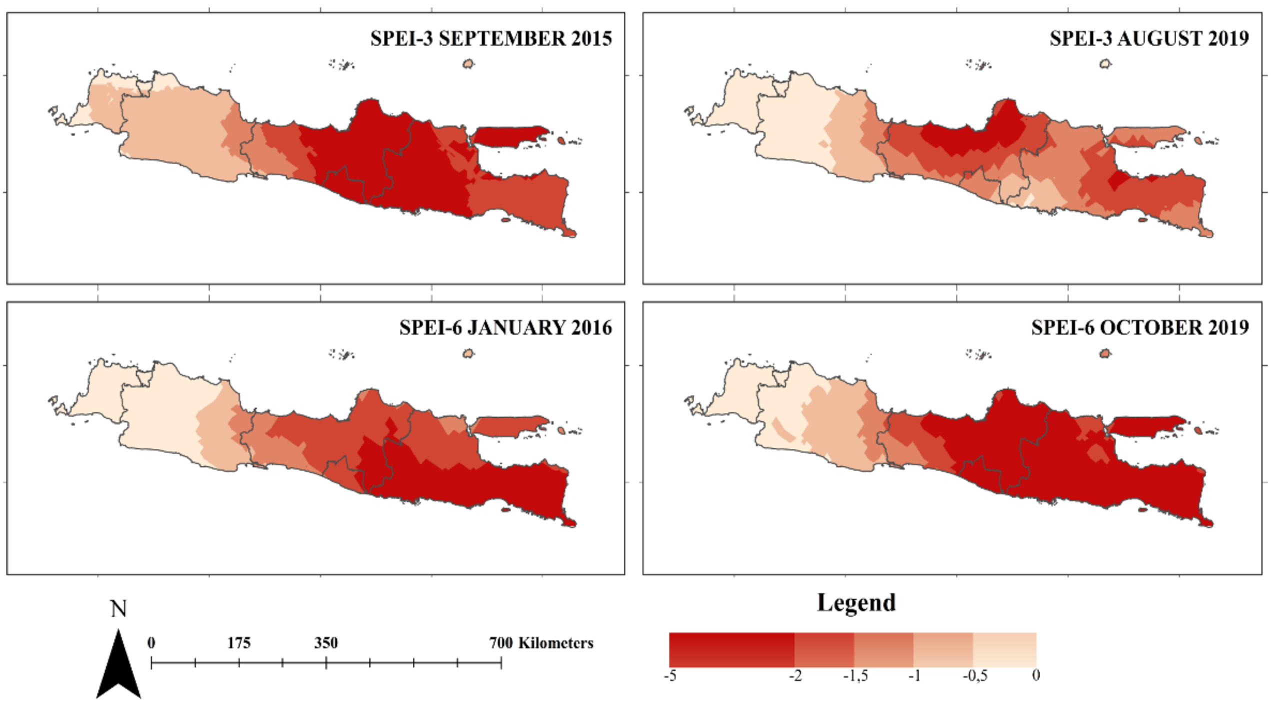

Figure 5 Spatial distribution of SPEI-3 and SPEI-6 values in the driest months.

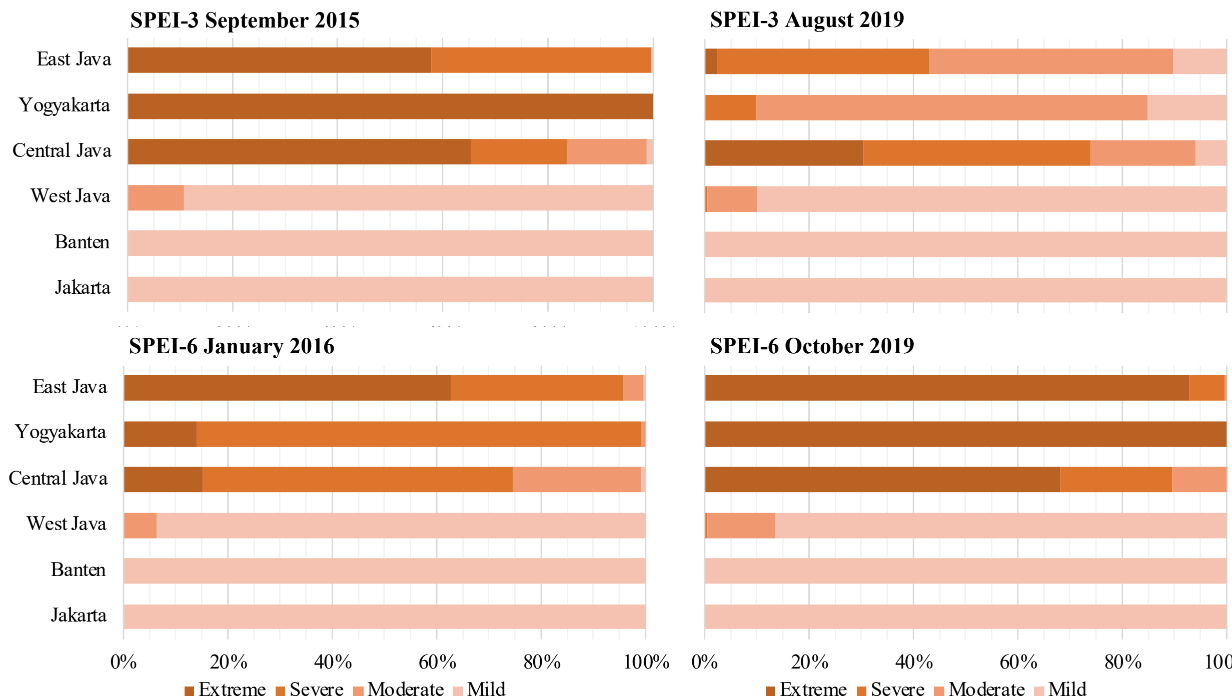

Figure 6 Percentage of the area with dryness level in the driest months in each province.

Table 2 Rice fields in each province affected by drought in 2019 and 2015

Region	Total agricultural area (hectares)	Drought affected area (hectares)	Percentage
Drought in 2015			
West Java	912,794	127,477	14.1
Central Java	965,261	64,044	7.5
Yogyakarta	53,553	369	0.8
East Java	1,091,752	28,973	2.9
Banten	199,492	25,345	12.7
TOTAL	**3,223,502**	**246,208**	**8.0**
Drought in 2019			
West Java	928,218	71,338	7.7
Central Java	1,049,661	74,272	7.2
Yogyakarta	76,273	10,943	14.4
East Java	1,214,909	42,695	4.0
Banten	204,335	24,557	12.2
TOTAL	**3,473,810**	**223,805**	**6.7**

4. CONCLUSION

Droughts occur on the island of Java regularly. Dry events with moderate to extreme levels are always followed by a significant area of paddy fields affected by drought. There have been two extreme droughts in the recent ten years, specifically in 2015 and 2019. It appears that considerable progress is being made in mitigating drought impacts, particularly in the agricultural sector. It is demonstrated by rice field areas impacted by drought, which tends to decrease compared to before 2010, although the intensity of the drought has increased. Support from stakeholders and technological developments have increased resilience to drought disasters. From a spatial perspective, the meteorological drought in eastern Java is more severe than in western Java. Drought, on the other hand, had a far higher impact on rice crops in western Java. Therefore, the west part of Java, especially Banten, requires specific attention and management to develop drought resilience. Furthermore, the Special Region of Yogyakarta also needs special attention because the impact of the drought in 2019 was much more significant than in 2015.

AUTHORS' CONTRIBUTIONS

Endita Prima Ari Pratiwi wrote the article. Candra Kusumasari Wisnu Murti contributed to collecting and organizing data, while Ellyana Inggrid Widiastuti created the maps and performed spatial analysis.

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