The Spatial and Temporal Analyses of Agricultural Drought in Paddy Rice: A Case Study in Indonesia

Amalia Nafisah Rahmani IRAWAN[1], Daisuke KOMORI[2] & Vempi Satriya Adi HENDRAWAN[1]

[1]Graduate School of Environmental Studies, Tohoku University, Miyagi 980-8577, Japan.
[2]Department of Civil and Environmental Engineering, Tohoku University, Miyagi 980-8577, Japan.
[*]E-mail: amalia.nafisah.rahmani.irawan.q3@dc.tohoku.ac.jp

Paddy is one of the primary food sources in the world, including in Indonesia. Located in the tropical-humid region, as the main agricultural production, the planting season for paddy is divided into the wet cropping season and the dry cropping season. The crop productivity is relatively higher in the dry cropping period due to the availability of sunlight and fewer clouds which support the crop growth. But there is a high risk of drought that could affect crop production because the water supply often relies on precipitation especially during the rainy season. Standardized Precipitation Index (SPI) is a famous drought assessment method found by McKee et al., in 1993 which only requires long-term precipitation data for the input, and it can be used to assess the agricultural drought. The SPI analysis was conducted using GSMaP precipitation data which has 0.1° spatial resolution. Then, the Pearson correlation was assessed between SPI Index and the drought-affected areas to determine the appropriate temporal scale and between SPI Index and detrended crop yield to examine the spatial response of wet crop to drought. The result of this research showed that SPI-3 in August is the most suitable to assess the agricultural drought in Indonesia. For the spatial response, the threshold value was determined with r = 0.6, where the region with r-value less than the threshold indicated the area which was more resilient to drought and the region with r-value higher than the threshold indicated the area which was more vulnerable to drought. The importance of the irrigation system was also found in this research.

Key Words : *Agricultural Drought, SPI, Paddy, Temporal Scale, Spatial Scale.*

1 Introduction

Agricultural drought started from the lack of precipitation (meteorological drought) that damaged the agriculture area and affected the crop production. Standardized Precipitation Index (SPI) was found by McKee et al., in 1993 that can be used for drought assessment and only needs the long-term precipitation data (minimum 20-30 years). By using the probability density function and normalization, the SPI can assess the wet and dry conditions over any regions (drought occurred where SPI ≦ -1). Another benefit of SPI is the temporal versatility so it can be calculated for various timescale according to user's interest (WMO, 2012).

Many researchers also have used SPI for agricultural drought assessment, but there is no general agreement reached to determine the most appropriate timescale to be utilized. For example, Ali (2001) and Ji and Peters (2003) found that SPI-3 is suitable in Turkey and U.S. Great Plains respectively. Meanwhile Iglesian and Quiroga (2017) use SPI-12 as a climate indicator for measuring the climatic risk to cereal production. Still, there is less discussion related to the agricultural drought on wet crops (e.g., paddy). Located in the tropical-humid region, paddy is the main agricultural production in Indonesia. The crop productivity is relatively higher in the dry cropping period due to the availability of sunlight and less clouds which support the crop growth. But there is a high risk of drought that could affect the crop production because the water supply often relies on precipitation especially during the rainy season.

In this research, the objectives are i) to determine the most suitable SPI index to be utilized for agricultural application in the tropical-humid region, ii) examine the spatial response of wet crop to agricultural drought on city-scale and grid-scale. Specifically, this study was focused on the paddy crop during the dry cropping period. This research was conducted in West Java as one of the largest rice producers in Indonesia with the rainy season from October - March and the dry season from April - September. According to the World Bank in 2016, 31.46% of the land is agricultural land, dominated by paddy fields, which is very vulnerable to drought events. The results of this study will be helpful to get a better understanding about agricultural drought impact on wet crops.

2 Materials and methods

The precipitation data collected from Japan Aerospace Exploration Agency (JAXA) provides near real-time rainfall data on their product called Global Satellite Mapping of Precipitation (GSMaP). The daily precipitation data are available from March 2000 - present date and were retrieved across West Java with 0.1° resolution. The agricultural statistical dataset in this study, drought-affected areas during the dry season and the crop yield (annually and monthly), were obtained from the Ministry of Agriculture and the Agricultural Agency of West Java respectively.

SPI was calculated based on the GSMaP precipitation dataset for various timescale (SPI-1, SPI-3, SPI-6, SPI-9, and SPI-12) with different month reference from January - December which is associated with the dry cropping season. To determine the most suitable SPI index, Pearson correlation analysis was assessed between various SPI index and drought-affected areas on the city-scale. For the grid-scale analysis, crop yield estimation model was generated using stepwise multilinear regression model from the vegetation indices or the Normalized Difference Vegetation Index (NDVI) obtained from MODIS/TERRA with 250-m resolutions. Then, the correlation analysis was conducted between SPI-3 and detrended crop yield to assess the impact of drought on paddy in Indonesia.

3 Results and discussion

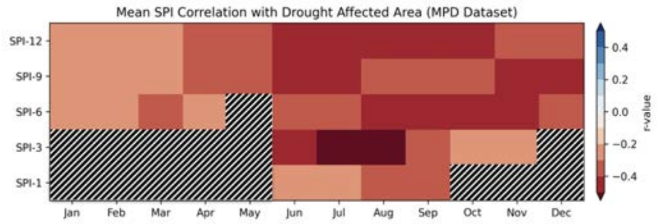

Fig. 1. Heatmap of Mean of Correlation Value between SPI Index and Drought-Affected Areas

Figure 1 showed the heatmap of average correlation value where vertical axis indicated the SPI aggregation timescale and horizontal axis indicated the month reference. The shaded area on the heatmap involved only a wet season which is not a target period of this study, so the result is not included. Based on the heatmap, the correlation resulted in negative values, indicated by the red colour, meaning that the decrease of SPI index, or a dry condition, is associated with the increase of drought-affected areas in the agriculture area. In addition, the highest correlation was found during the SPI-3 in August thus in this study SPI-3 was selected as the most suitable index to be utilized. This finding is consistent with study by Ali in 2013 which stated that SPI-3 is sensitive to the reduction in soil moisture that affects crop growth and with study by Ji&Peters in 2002 which stated that vegetation has a time lag response to precipitation and that the impact of water deficits is cumulative.

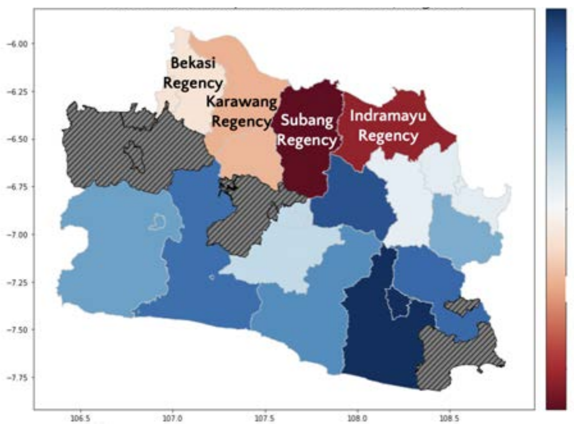

Fig. 2. Spatial Distribution of r-Value between Detrended Crop Yield and SPI-3 on City-Scale

After the most suitable SPI index was determined, the correlation between crop yield and SPI-3 was assessed on city scale. The result did not produce a high significant correlation caused by the spatial scale of the assessment and the uncertainty in the subround dataset. But the different response in the northern area (irrigated by dam) and southern area (irrigated by river or wells) was observed. This result indicates the importance of an advanced irrigation system. In the northern part, severe drought events did not result in a high crop yield loss because there is still water supply for agricultural activity resulting in negative correlation.

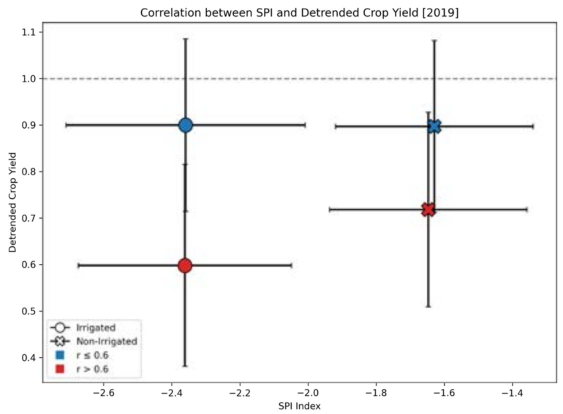

Fig. 3. Correlation between Detrended Crop Yield and SPI-3 in 2019 on Grid-Scale

For the grid-scale analysis, 2019 was selected to be the focus period because of the occurrence of the most extreme drought year. Based on the characteristics of the data from grid-scale analysis, it was observed that almost all the grid located in region with r-value ≥ 0.6 experience crop yield loss with various SPI index values indicating the drought event as the driver of crop yield loss, thus the threshold for r-value was set at 0.6. Figure 3 showed the result from grid-scale analysis with 4 main findings: (1) The irrigation system was installed in the area which was hit by drought the hardest (more to the left). (2) Region with r-value ≥ 0.6 was more vulnerable to drought, which might be caused by failure in delivering an adequate amount of water (as proven by the red circle marker) or other still unknown factors. (3) Region with r-value < 0.6 was more resilient to drought, proven by the blue circle marker which has low crop yield loss even after being hit by severe drought. (4) Meanwhile the region which is still irrigated by local water resources (cross shaped marker), even though it is not located in the extreme dry region, the water availability is still very dependent on precipitation that might be dangerous in the future because of climate change impact.

4 Conclusion

This study was conducted to assess the temporal and spatial response of the wet crop to the agriculture drought during the dry cropping season. SPI-3 in August is the most suitable index to be utilized and the assessment is recommended to be conducted on grid-scale because there are many local characteristics in fragmented agriculture areas. Based on the correlation between SPI-3 and crop yield, the threshold for r-value was set for 0.6. For the region which is more vulnerable (r-value ≥ 0.6), the existence of irrigation systems cannot withstand the drought event resulting in higher crop yield loss when hit by more severe drought. Meanwhile, for the area which is more resistant (r-value < 0.6), the low crop yield loss was observed both in irrigated and non-irrigated agricultural areas.

5 References

[1] World Meteorological Organization, 2012: Standardized Precipitation Index User Guide (M. Svoboda, M. Hayes and D. Wood). (WMO-No. 1090), Geneva.

[2] Ji, L., & Peters, A. J. (2003). Assessing vegetation response to drought in the northern Great Plains using vegetation and drought indices. Remote Sensing of Environment, 87(1), 85–98.