Agricultural drought risk assessment in upper progo watershed using multi-temporal landsat 8 imagery

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Abstract. Upper Progo watershed is one of the important agricultural areas in Temanggung Regency, Central Java. This research used the data obtained from Landsat 8 imagery to analyze the agricultural drought risk in the watershed. The hazard was analyzed using multi-temporal data every 16 days (to the Landsat 8’s temporal resolution) during the drought; from May to September 2015 combining the Landsat 8 imagery and the land’s physical condition. An agricultural drought hazard map was then created by summing the hazard class score in every recording time with overlay method. The crop’s vulnerability analyzed using NDVI difference, which indicates the crop’s ability to survive in dry conditions. The crop's vulnerability was also analyzed every 16 days. A vulnerability map was then created by summing the vulnerability class of every recording time. The assessment of the drought risk was done by multiplying the hazard and the vulnerability scores. The result shows the high and very high classes of agricultural drought risk were located on the west research area which had a high class of hazard and vulnerability. Meanwhile, the moderate, low, and very low classes of agricultural risk were distributed evenly in the center and east area.

1. Introduction

Water is a component of life that is very important for the survival of every living thing. It will always be available in an area because of the hydrological cycle. One of the stages in hydrological cycle is precipitation. Precipitation is the main water source that supplies water in a catchment area in the tropics. Reducing the amount of precipitation will cause a reduction in the number of water reserves on land in the forms of soil moisture, surface runoff, and ground water. This might cause drought. Drought occurs in all climatic zones, both in areas with high and low rainfall associated with a reduction in the amount of precipitation received over a certain period, e.g. in one season or one year [7].

Drought has countless definitions because of its universal nature. Three of them are elaborated as follows. First, drought is a naturally occurring phenomenon that occurs when rainfall falls significantly below the normal levels causing serious hydrological imbalances and reduces land production systems (UN Convention to Combat Drought and Desertification, 1994) [7]. Secondly, drought is a type of complex hazard caused by the disruption of water balance and impacts on agriculture, ecology, and socio-economy [4]. Third, drought is a type of disaster that has special characteristics because it takes place slowly and propagates. The level of preparedness and mitigation of drought depends on the information about the onset and propagation of drought in time and space [8]. This promotes the urgency of the study of drought in space and time to improve the preparedness and mitigation should drought happens.
Agricultural drought is one type of drought besides meteorological, hydrological, and socioeconomic droughts. Agricultural drought is associated with a reduction in water content in the soil (soil moisture) so that it is no longer able to meet the water needs of plants in a certain period. This drought occurs after the symptoms of meteorological drought [1]. Unless it is handled properly, agricultural drought will cause hydrological and socio-economic droughts. Agricultural drought is a complex climate phenomenon and often occurs when rainfall and soil moisture are insufficient to meet the water needs of plants. Drought physiologically and morphologically affects vegetation but there is a pause in vegetation response due to drought is the accumulation of gradual processes. The situation of vegetation growth during an observation is an effect of the combination of the previous conditions [15]. The low value of precipitation coupled with the high value of evapotranspiration results in low soil moisture [7].

Agricultural drought will disrupt agricultural activities and productivity which in turn will affect the availability of food [6]. Agriculture is the first sector affected by the onset of drought due to plant’s dependence on water resources and soil moisture during different stages of plant growth [5]. The early period of planting under drought conditions has become a recurring event in tropical countries due to monsoon fluctuations at the onset of the dry season [3].

An agricultural drought that occurs on productive land might pose a disaster risk. Disaster risk can be defined as a possible consequence of danger or loss (death, injuries, house, livelihood, disruption of economic activity, or environmental damage) as a result of interactions between (natural, human error) hazards and conditions of vulnerability [11]. Agricultural drought is called a danger because it is a natural phenomenon in the form of decreased soil moisture level that might threaten human survival because it might cause crop failure. The vulnerability of agricultural drought refers to the inability of plants to survive against soil deficiencies. The result of the interaction between the hazards and vulnerabilities of agricultural drought is the risk of agricultural drought, which is a potential consequence of losses due to crop failure caused by the inability of the crops to withstand the lack of soil moisture.

The application and use of remote sensing to estimate drought have been growing rapidly particularly after the development of satellite systems and their capabilities [16]. Remote sensing methods and techniques can be used to assess several aspects of drought, including vulnerability, damage, and warning systems [2]. The main consideration of using remote sensing methods for drought assessment and disaster risk reduction is the wide openness of users who can continuously supply the data [2]. The accuracy in temporal monitoring, spatial distribution, and the severity of drought can provide an effective meaning in reducing farmers’ losses [14].

The Progo Hulu watershed is an important agricultural area in Temanggung Regency due to the vast available agricultural land. The 2015 dry season caused many villages in the region experienced drought. This condition prompted the Temanggung Regency Government to establish a drought emergency based on the Temanggung Regent Decree No. 337/2015 concerning a 90-day drought emergency set on August 1, 2015 [10]. The basis for establishing this emergency was many villages were experiencing drought, and as a result, many people lacked clean water and agricultural land could not be cultivated [9].

2. Methods
The analysis of the risk of agricultural drought in Upper Progo watershed consisted of several stages as risk analysis and hazard and vulnerability analyses are inseparable. Each of the stages carried out in this study is elaborated as follows:

2.1. Meteorological Drought Analysis
The meteorological drought analysis was used to estimate the beginning and end of the duration of the drought. The duration of drought was used as the basis for analyzing Landsat 8 Imagery. The duration of rainfall deficit was analyzed using a water balance graph between monthly rainfall and evapotranspiration rate calculated using Thornwaite formula. Drought begins when the evapotranspiration value is higher than the amount of the rainfall and ends when the precipitation exceeds the evapotranspiration value.
2.2. Agricultural Drought Hazard Analysis

The hazard analysis was carried out by utilizing Landsat 8 OLI imagery following the period of meteorological drought that had been analyzed previously. On the ground that Landsat 8 imagery has a temporal resolution of 16 days, the imagery analysis was carried out every 16 days; then the changes in the pixel value of the imagery were observed at each recording date. A pixel analysis to determine the drought hazard using iTVDI index has been carried out by [12] in the same research area. The study revealed changes in the pixel value at each recording date and modeling the propagation of soil moisture deficits which could be used as a basis for making a hazard map of agricultural drought.

The determination of the hazard of agricultural drought in the Upper Progo watershed was determined by scoring method. The hazard scoring was obtained from the sum of the class of the soil moisture condition scores from the model that had been made every 16 days. The soil moisture condition of the modeling was categorized into 5 classes based on the value of iTVDI. The class division employed the equal interval method i.e. set the same class length for each class. The iTVDI class (soil moisture condition) is presented by Table 1.

| No | iTVDI value | iTVDI class | Score |
|----|-------------|-------------|-------|
| 1  | 0.0 – 0.2   | Wet         | 1     |
| 2  | 0.2 – 0.4   | Slightly wet| 2     |
| 3  | 0.4 – 0.6   | Normal      | 3     |
| 4  | 0.6 – 0.8   | Slightly dry| 4     |
| 5  | 0.8 – 1.0   | Dry         | 5     |

Source: Research 2015

The map of iTVDI which had been classified into soil moisture class and given a score was then overlapped. The overlapping analysis was done by adding up the spatial score of each recording date. The total score resulted in a map of agricultural drought. The map was then classified into the class of agricultural drought. The classification was done by the quantile method in ArcGIS 10 software. Table 2 presents the classification of agricultural drought hazards using the quantile method.

| No | iTVDI’s class score | Hazard class | Hazard score |
|----|---------------------|--------------|--------------|
| 1  | 9 – 17              | Very low     | 1            |
| 2  | 17 – 18             | Low          | 2            |
| 3  | 18 – 22             | Moderate     | 3            |
| 4  | 22 – 28             | High         | 4            |
| 5  | 28 – 38             | Very high    | 5            |

Source: Research 2015

2.3. Agricultural Drought Vulnerability Analysis

The analysis of agricultural drought vulnerability was undergone by identifying leaves withering on the plants. Leaves withering on plants can be identified using the difference of NDVI values. Research on plant vulnerability in the study area by using NDVI differences was conducted by [13]. The division of vulnerability class scores based on NDVI difference values can be seen in Table 3. Vulnerability classes were then scored for the purpose of the overlapping analysis to determine the risk of agricultural drought: the higher the class of vulnerability, the higher the score, and vice versa.

| No | NDVI percentage decrease | Vulnerability class | Vulnerability score |
|----|----------------------------|---------------------|---------------------|
| 1  | > 33,3%                    | Very high           | 5                   |

Source: Research 2015
2.4. Agricultural Drought Risk Analysis

The analysis of the risk of agricultural drought is the result of the interaction of the value of hazard and that of vulnerability. The risk of agricultural drought was obtained by the equation:

\[ \text{Risk} = \text{Hazard} \times \text{Vulnerability} \]

The results of the multiplication of hazard class map and risk class map were then reconfigured to determine the class of the risk of agricultural drought in the research area. The agricultural drought risk maps were the results of overlapping of the hazard map and the agricultural drought vulnerability map. The scores of agricultural drought risk were obtained by multiplying the hazard scores and the vulnerability scores. The high-risk scores occur when the high hazard overlap with high vulnerability. The division of risk classes was made based on the division of classes using the Natural Breaks method after the final risk score was obtained. The division of classes of agricultural drought risk using the Natural Breaks method is shown by Table 4.

| No | Risk score | Risk class |
|----|------------|------------|
| 1  | 1 – 4      | Very low   |
| 2  | 4 – 6      | Low        |
| 3  | 6 – 10     | Moderate   |
| 4  | 10 – 16    | High       |
| 5  | 16 – 25    | Very high  |

Source: Research 2015

3. Results and Discussion

3.1. Meteorological Drought in the Upper Progo Watershed in 2015

A water balance graph was made by comparing the amount of rainfall with that of the evaporation. The potential evaporation was calculated using the Thornwaite method. The results show that the amount of potential evaporation was approximately 130 mm. In relation to the onset of the meteorological drought in the Upper Progo watershed, the sources were divided into two: 5 rain stations detected the start of the drought in May, while the other 3 stations detected it in June. The beginning and end of the meteorological drought were used as a basis to start the analysis of Landsat 8 imagery to detect the soil moisture deficits which functioned as an indicator of the agricultural drought in the upper Progo watershed. On the grounds that Landsat 8 temporal resolution is 16 days, the analysis of the agricultural drought was carried out every 16 days during May to November 2015.

3.2. Agricultural Drought Hazard in the Upper Progo Watershed

Figure 1 shows that the high and very high hazard classes were located on the west of the study area. This area covered the volcanic area of Sindoro and Sumbing which had the smallest soil moisture over time compared to the rest of the study area. Based on the multi-temporal analysis, this area always had a high iTVDI value. This indicates that the Sindoro and Sumbing volcanic areas were more easily experiencing soil moisture deficits than the other regions of the study area should rainfall deficit occurred. A soil moisture deficit might affect the agricultural output or cause fire on land planted with annual crops.
The area that belonged to moderate hazard class is located on the eastern part of the study area. This area was dominated by plantations and dry fields. This region had the potential for a higher soil moisture deficit than the central region. This signifies that the eastern region had a tendency to experience a soil moisture deficit faster than the middle area of the study area. The central part of the study area was an area classified into low and very low agricultural drought hazard classes. Soil moisture deficits did not occur quickly in this area should rainfall deficits occurred. This area was an area with good technical irrigation so that it had the adequate water supply. The extent of each agricultural drought hazard class in the study area is shown in the graph presented in Figure 2.
The graph indicates that the majority of the area of the study belongs to low hazard class, while the narrowest area belongs to a very low hazard class that has a considerable difference in the coverage with the other four classes. It also shows that the difference of the moderate hazard class coverage and that of the low class is not too big. The coverage decreases in the high and very high classes in comparison with the aforementioned classes, but it is not quite significant.

3.3. The Vulnerability of Agricultural Drought in the Upper Progo Watershed
Figure 3 shows the very high vulnerability class, shown in red, dominates the western part of the study area that covers the Sindoro and Sumbing volcanic slopes. The high level of vulnerability in this area occurs because the plants were unable to absorb water from the soil due to their short roots. In addition, high levels of vulnerability are usually experienced by seasonal crops of which roots are only able to reach the topsoil. However, the high vulnerability indicated by the significant decrease in the NDVI value was not only shown by the seasonal plants. The significant decrease was also found in hard trees due to the long days of rainfall deficit. Hard trees that on the average possess a high NDVI value due to their thick leaves are unable to maintain their leaves. Plants have to maintain their lives in a state of water deficit. They must reduce the evaporation (transpiration) by shedding their leaves. The number of fallen leaves causes the NDVI values to drop significantly, so this area also had the high drought vulnerability.

Figure 3. Map of agricultural drought vulnerability in the Upper Progo watershed
Figure 4. The coverage of agricultural drought vulnerability classes in the Upper Progo watershed

The vulnerability classes were divided into 5 with their respective coverage as it is presented in Figure 4. The high vulnerability class is the most extensive area among the other classes of vulnerability.

3.4. Agricultural Drought Risk in the Upper Progo Watershed

The risk of agricultural drought is the result of the interaction between the hazard and vulnerability of agricultural drought. The high risk occurs when the soil moisture easily experiences deficits, while the plants easily wither which are indicated by the decrease in the NDVI values. Agricultural drought risk maps are the result of the overlapping of the hazard map and the agricultural drought vulnerability map.

Figure 5. Map of agricultural drought risk in the Upper Progo watershed
Figure 5 shows that the risk of agricultural drought in the Upper Progo watershed was located in the western part of the study area or the Sindoro volcanic slope and foot area. This area had a high risk of agricultural drought due to low evapotranspiration rates (soil moisture is easily reduced) combined with easily wilted plants (seasonal crops). Seasonal plants have a little canopy cover so that the sunlight will quickly reach the ground and cause the quicker reduction of the soil moisture. The high risk of agricultural drought became the significant limiting factor in influencing the productivity of the agricultural land in this area.

Sindoro volcanic slopes and foot had a higher risk of agricultural drought than those of Sumbing which is shown by the dominance of the striking red color. This occurs on the grounds that vulcan Sindoro is younger than that of Sumbing, so the shape of the land of the Sumbing volcano is relatively more stable due to the longer geomorphic process. A proper and integrated management is urgently needed to maintain the water supply because the Sindoro Sumbing volcanic area is a rain catchment area that affect the quality and quantity of the water underneath.

Very low and low-risk classes were located in the middle and south of the study area. The central part of the research area was an area with a good irrigation system so that the water supply for the plant growth is more accessible than that of the other parts of the study area. The middle part is the center of rice production which is a seasonal crop that has high drought vulnerability, so this area has a low to very low risk. The low-risk class was mostly located in denuded hill remnant and volcanic remnant which were mostly annual plants.

The eastern part of the research area which had moderate risk covered dry fields and gardens. The dry field had a high vulnerability because the plants were in the form of seasonal crops, while the garden had a lower vulnerability due to its annual plants that had longer roots. The central and eastern parts, despite their lower class of agricultural drought risk, compared to the western part of the study area, without the good and appropriate management, the risk class might change to high. The coverage of each agricultural drought risk class in the Upper Progo watershed is presented by Figure 6.

Figure 6. The coverage of the agricultural drought risk classes in the Upper Progo watershed

The information on the spatial distribution of the risk of agricultural drought in the Upper Progo watershed can be taken into consideration by the policymakers who will carry out the programs for the regions with a high risk of agricultural drought in the Upper Progo watershed. Programs on community empowerment on reducing the impacts of agricultural drought can be carried out in the areas with a high risk of agricultural drought. Planning to reduce the risk of agricultural drought can also be done by building reservoirs in the areas that are rapidly losing soil moisture after a rainfall deficit occurs.

4. Conclusion
The high and very high classes of drought risk were located on the western part of the study area because this area had high hazard and vulnerability. That of the moderate class was in the eastern part, while the low and very low-risk classes were in the middle of the study area. The coverage distribution of the risk
classes of the agricultural drought in the Upper Progo watershed is as follows: very low (10683 ha, 18.8%), low (7448 ha, 13.1%), moderate (15619 ha, 27.5%), high (14555 ha, 25.62%), and very high (8492, 14.9%).

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