Spatiotemporal Pattern Distribution of Drought Area using MODIS Vegetation Health Index. Case Study: Paddy Field in East Java, Indonesia

AP Kirana†, ARTH Ririd1, R Ariyanto1, EL Amalia1, Bhawiyuga A2

1Information Technology Department State Polytechnic of Malang East Java, Indonesia
2Faculty of Computer Science, University of Brawijaya Malang, Republic of Indonesia

*Corresponding author: puspakirana@polinema.ac.id

Abstract. Drought is the main natural disasters in Indonesia. Study of spatial and temporal drought pattern distribution is great significance for disaster prevention and mitigation. Agricultural drought assessment was used to monitor agricultural sustainability, particularly in East Java as the national centre for agricultural production in Indonesia. This study aimed to detect the spatial and temporal pattern of agricultural drought using Vegetation Health Index (VHI) and illustrated drought characteristics in East Java, Indonesia during 2017-2018. In this research, we use LST and EVI data from MODIS Terra satellite data. We used LST for calculating TCI, and EVI for calculating VCI. VHI were obtained by TCI and VCI score. The result showed that all drought-affected areas were experienced by moderate droughts. Bojonegoro, Magetan and Gresik district has the highest drought level compared to another district in East Java. Drought area increased significantly in September to October, which is dry season in Indonesia and cover 69.13% of agricultural area.

1. Introduction
Drought is a phenomenon that affects many areas of the world, particularly in most areas of Indonesia and it is a natural disaster that occur frequently in Indonesia [1]. The dry season in Indonesia has never been easy, and it often happens in almost every year. Severe drought gives bad consequences for water supply, food production as well as the environment [1]. Some negative effects of Indonesia's drought disaster are forest fires, searing heat and air pollution. Due to these serious consequences, severe monitoring of droughts is very important in order to mitigate and avoid the effects of drought. To reduce the impact of droughts, a better understanding of drought characteristics such as Which region has a high drought intensity is required? When does it happen? How is distribution pattern of drought spatially and temporarily? The estimation of drought characteristics over a region is necessary to answer these questions and analyzing remote sensing data is very helpful in obtaining such estimates. To answer these questions, estimating the characteristics of drought over a region is needed and analyzing remote sensing data is very helpful in obtaining such estimates. In this study we analyzed the distribution of spatiotemporal patterns of drought especially in East Java, Indonesia. Java island sustains the most fertile soils in the country and food production depends highly on this island. Due to some natural hazard and increasingly rapid population growth which frequently occurs, such as
drought, it puts pressure on the stability of agricultural land in East Java and it gives bad impact on national food security [5].

Drought can be monitored effectively over large areas with remote sensing technology. Remote sensing is a useful tool for monitoring changes in land use, deforestation and natural disasters such as drought, floods, soil erosion and so on [2]. Drought monitoring is essential to minimize and prevent the impact of drought occurrence. This information would help planners reduce the negative impact of drought disasters. Previous study about drought monitoring system, especially for drought mapping have been developed and applied. Running et.al [3] developed drought mapping system using Land Surface Temperature (LST). LST was used as criterion for evaluating vegetation status and development. The use of the LST index is significant because the temperature of the earth's surface influences vegetation growth [3]. Another drought index that has been used is Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) in [4]. AghaKouchak et.al proposed models and algorithms that combine multiple data from satellite observations into model simulations to generate long-term climate data records based on NDVI and EVI level [4].

This study used Vegetation Health Index (VHI) indices from Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data. VHI represents overall vegetation health. Drought mapping using VHI index is better than using only single drought index indicator [10]. Study of agricultural drought in East Java is expected to be used as an early warning of drought and mitigation measures to reduce the effect of drought on sustainable agriculture. This study has two main objectives: First, to get the spatial and temporal distribution of drought area especially in East Java, Indonesia. Second, to recognize the distribution pattern of drought area clusters in East Java between 2017 to 2018 using Kulldorff’s Scan Statistic (KSS) method.

2. Study Area
This study was located in East Java, Indonesia which consists of 29 districts and 9 cities. In the last 25 years, the agricultural sector in East Java has played a major role in Indonesia’s economic development [6]. East java is one of the six Provinces in Java Island which is known as natural producer of rice. East Java Province is expected to produce more than 16% of national rice [7]. This region located between 111°0’ – 114 °4’ east longitude and 7 °12 ’-8 °48’ latitude [8]. Total area of agriculture in East Java is approximately 23,309 km² which is consists of paddy fields (irrigation and non-irrigation areas), plantations, forests, grasslands, fields, unused areas, and other lands [8].

3. Data
We used LST and EVI from MODIS datasets to calculate remote-sensing-based drought indices. In this study, severe drought area was identified from 1 January 2017 until 31 December 2018. We calculated Temperature Condition Index (TCI) score from LST, then Vegetation Condition Index (VCI) score from EVI to obtain VHI score from TCI and VCI. MODIS datasets were obtained from U.S. Geological Survey (USGS). The monthly surface reflectance and LST data were used to calculate
respective EVI. EVI and LST time series have potential to describe the various dynamics of dry conditions. EVI and LST were used to calculate VCI and TCI. VHI was calculated from VCI and TCI. For spatiotemporal clustering process, we used date and location of each pixel from VHI dataset.

4. Methodology

4.1 Temperature Condition Index (TCI)

TCI was derived from LST. TCI value ranges 0-100. High value of TCI index represents healthy vegetation and low value of TCI index represents the vegetation stress due to high temperature. Monitoring TCI index is important to identify the soil moisture stress due to the high temperature which help to analysis the effect of temperature on vegetation health [9]. We obtained monthly LST from MODIS product MOD11C3. TCI can be measured using following formula [10]:

\[ TCI_i = \frac{\text{LST}_i - \text{LST}_{\text{min}}}{\text{LST}_{\max} - \text{LST}_i} \times 100 \]

where LST\(_i\), LST\(_{\text{min}}\) and LST\(_{\max}\) defined as LST of current month, and maximum and minimum LST value in multi-year. In several study, TCI is also produced from brightness temperature. TCI indicated the relation between the actual temperature value and the temperature that occurred in the potential (LST \(_{\text{min}}\)) and stress (LST \(_{\max}\)) crop conditions within the same period [9].

4.2 Vegetation Condition Index (VCI)

In this study we used MODIS product MOD11A3 monthly EVI dataset which has 1 km of spatial resolution. VCI was calculated using EVI. VCI has ranges from 0-100 representing relative changes in the vegetation condition from extremely poor to optimum condition [12]. Low VCI indicates a poor condition and high VCI indicates an optimum condition. VCI distinguishes short-term weather related EVI fluctuation from long-term shifts in the ecosystem [12]. EVI\(_i\), EVI\(_{\text{min}}\) and EVI\(_{\max}\) defined the maximum values of EVI of current month, it’s multiyear maximum and minimum respectively [14]. VCI can be measured using following formula [10]:

\[ VCI_i = \frac{\text{EVI}_i - \text{EVI}_{\text{min}}}{\text{EVI}_{\max} - \text{EVI}_i} \times 100 \]

4.3 Vegetation Health Index (VHI)

VHI is calculated from VCI and TCI which provide a better comprehension of the frequency of drought. In this study we used monthly LST to obtain TCI values and monthly EVI values to obtain VCI as shown in Figure 2. Monthly LST is obtained from MOD11C3 MODIS datasets and monthly EVI is obtained from MOD13A3 data sets. VHI represents overall vegetation health and it usually uses for drought mapping. Drought mapping using VHI index is better than using only single drought index indicator. VCI can be measured using following formula [10]:

\[ \text{VHI} = 0.5 \times (\text{VCI} + \text{TCI}) \]

VCI, TCI, VHI classified into five severity classes, i.e. extreme drought, severe drought, moderate drought, mild drought and no drought [12][13].

4.4 Spatiotemporal Clustering Process

We process the VHI dataset especially in the paddy field area of Kalimantan by considering spatial and temporal factors. Spatial factor refers to the location of each VHI’s pixel area with longitude and latitude attributes. Temporal attributes refers to occurrence time of VHI values with month attributes. We used Kulldorff’s Scan Statistic (KSS) method for clustering of both aspect, spatial and temporal data from monthly VHI distribution. KSS has been used conventionally in previous studies to
recognize pattern distribution of hotspots in Sumatra, Indonesia [14]. Data sets pre-processing consists of five steps; first step is to determine important attributes for the clustering process using Kulldorff's Scan Statistics (KSS) method. The second step is to select the monthly raster VHI data set with paddy field distribution, especially in East Java, as shown in Figure 3. Third step is to select the location of VHI distribution in each district, and last step is to load data into the database. We used 'spatialepi' R package [15] for clustering hotspot processes.

**Table 1.** Classification of VCI, TCI and VHI drought condition [12][13]

| Values | Severity Class   |
|--------|------------------|
| <10    | Extreme Drought  |
| <20    | Severe Drought   |
| <30    | Moderate Drought |
| <40    | Mild Drought     |
| >40    | No Drought       |

**Figure 2.** Flow diagram of VHI calculation

**Figure 3.** Preprocessing dataset

KSS generated large collection of circular windows called circular scanning window to detect clusters as shown in Figure 4. ‘μ(Z)’ is total population which located inside a circular scanning window, ‘μ(G)’ is total population which located inside the area of study ‘n’, ‘G’ is the entire area of study, ‘Z’ is a circular scanning window, ‘p’ is the average rate of occurrence event in a circular scanning a window, ‘nz’ is the number of cases in a circular scanning window ‘Z’, ‘nG’ is the number of cases in the study area of ‘G’ and ‘q’ is the rate of the event outside a circular scanning window. KSS method used to compare the number of case occurrences inside and outside scanning window. Comparison result is used to search hotspot cluster distribution in area study ‘n’ [16].
Figure 4. Study area and circular window [16]

5 Result

Figure 5 shows monthly distribution of VHI in East Java especially in the paddy field area. The green color indicates healthy vegetation while the red color indicates poor vegetation condition. The period of time that we use in this study is January 2017 to December 2018. We analyzed VHI value that has score less than 40 to detect cluster distribution of severe drought area from 38 district in East Java. We obtained 4 cluster of severe drought area in 2017. Highest density of VHI that has score less than 40 is in Bojonegoro (primary cluster). Secondary cluster were occured in Magetan, Gresik, and Tuban. Figure 5 shows cluster distribution of VHI from January to December 2017 that consist of 4 clusters.

![Figure 5. Monthly distribution of VHI in 2017](image)

We obtained 5 cluster of severe drought area in 2018. Highest density of VHI that has score less than 40 is in Bojonegoro (primary cluster). Secondary cluster were occurred in Lamongan, Magetan, Gresik, and Ngawi. Figure 6 shows cluster distribution of VHI from January to December 2018. From 2 years distribution revealed that some area such as Bojonegoro, Magetan and Gresik always has high density of VHI values with less than 40 score.

VHI describes vegetation health from the combination of TCI (temperature) and VCI (vegetation condition). As shown in Figure 7, the monthly VHI analysis results in 2017 reveal that the maximal average is 59.44 on January, which is rainy season, while the minimal average is 42.06 on September, which is dry season. VHI analysis results in 2018 reveal that the maximal average is 56.92 on January,
which is rainy season, while the minimal average is 36.41 on October. Figure 7 indicated the level of drought from mild drought to severe drought.

![Figure 6. Monthly distribution of VHI in 2018](image)

![Figure 7. Average monthly VHI score 2017 – 2018](image)

Drought areal extent of VHI in 2017 to 2018 was tend to high in July to October (dry season). In 2017, the highest drought distribution area occurred in September which cover 64.13% of agricultural area. In 2018, the highest drought distribution area also occurred in September which cover 69.13% of agricultural area. Figure 8, represents about drought area distribution that has severity class of: mild drought, moderate drought, severe drought, and extreme drought area. Based on VHI value in 2017 to 2018 the drought maps in agricultural area of East Java were dominated by moderate drought.
Figure 8. Percentages of total drought area distribution

6 Conclusion
Clustering VHI indices in paddy field area in East Java from 2017 to 2018 using KSS method discovers patterns of VHI indices clusters distribution. Agricultural drought in East Java usually occurs in July to October which is a dry season in Indonesia. Based on spatial aspect from KSS clustering result, we obtained that cluster distribution of severe drought regions are in Bojonegoro, Magetan and Gresik. Cluster distribution from 2017 to 2018 dominated by ‘moderate drought’. Based on temporal aspect, from 2017 to 2018 percentages of drought area increased significantly in September which cover 69.13% of agricultural area. Based on VHI value in 2017 to 2018 the drought maps in agricultural area of East Java were dominated by moderate drought. The overall results and analyses suggested that crop farmers should be informed about the occurrence of drought as an early warning or mitigation. Lacking such information can lead to crop failures and affect food security in Indonesia.

7 References
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