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Agricultural drought monitoring based on vegetation health index in East Java Indonesia using MODIS Satellite Data

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Abstract. Agriculture is among the most vulnerable of all sectors to drought. Droughts cause serious effects on the agricultural sector due to its heavy dependence on rainfall. In the present work, we use the Vegetation Health Index (VHI) of MODIS Data as drought indices to monitoring the drought over East Java, Indonesia. VHI is computed based on the vegetation index and land surface temperature which are very important satellite products for drought monitoring with remote sensing. VHI describes vegetation health from the combination of TCI VCI. Based on VHI monitoring drought area distribution increase 3.69% in period 2017-2018. The highest distribution of drought area occurs in July to October. Average distribution of drought area is 22.24% in 2017, and 25.93% in 2018 from total wide 1.174,586 km2 of paddy field area. Based on VHI value in 2017 to 2018 the drought maps in agricultural area of East Java were dominated by moderate drought.

1. Introduction

Indonesia is the world's largest archipelago scattered between 60 north latitude to 110 south latitude and from 90 to 1410 east longitude and has more than 17,500 islands. Indonesia is agricultural country which food production depends highly on Java Island. Java island sustains the most fertile soils in the country, but had limited area and it has been the main food provider of the country. Due to increasingly rapid population growth and some natural hazard which frequently occurs, such as drought, it puts pressure on the stability of agricultural land in East Java and this thing give bad impact on national food security [1]. Indonesia is located in a part of the earth with tropical climate which is highly sensitive to the anomaly climate of El-Nino Southern Oscillation (ENSO). Most parts of the country have a wet humid tropics climate with a rainy season, the west monsoon, between October and March. A dry season, the southeast monsoon, between April and September. Drought and severe vegetation stress in Indonesia related with ENSO. Because of that, ENSO also had significant consequences for rural income, agricultural production, and stability food price [2]. ENSO phenomenon can cause drought [3]. The drought disaster in Indonesia happens frequently and almost in every year. The major cause of drought is low precipitation level, which often recurs every cold season until hot season [4]. Drought can bring some negative impact for water supply, food production and the environment as a whole [5]. Because of these serious consequences, severe droughts in the recent past have gained wide attention.

In order to minimize further risk and potential hazards, it is necessary to monitor and assess drought using scientific tools. Drought monitoring is essential to minimize and prevent the impact of drought occurrence. A drought monitoring is designed to identify water supply trends and climate. This monitoring system can detect the emergence or probability of occurrence and the likely severity of drought [6]. Drought can be monitored effectively over large areas using remote sensing technology. Remote sensing technology is modern and up-to-date technology that is able to apply to many situations, especially natural disaster prediction such as drought, flooding, soil erosion and etc. [7]. Remote sensing is really important for the drought monitoring system. Satellite based remote sensing data provides a synoptic view of Earth surface, and therefore can be used to evaluate drought occurrence spatially [8]. Several remotely-sensed drought indices have been developed and applied, which include intensity, severity, duration, and spatial extent [9]. The satellite-based information is helpful to monitor drought over location with limited measuring gauges and improve the assessment of drought severity with higher spatial and temporal resolution [10].

Previous drought monitoring system have been developed and applied for example Enhanced Vegetation Index (EVI) [11] and Normalized Difference Vegetation Index (NDVI) have been used for drought mapping [12]. EVI and NDVI indices monitoring through measuring canopy structural variations and photosynthetic activity [11]. Another drought index that has been used is Land Surface Temperature (LST). LST have been used as criteria, for evaluating the status and development of vegetation because [13] using LST index is important because earth's surface temperature influences vegetation growth. VHI (Vegetation Health Index) is drought index derived from remote sensing which popularly used. VHI is a combination of other two drought indices, specifically TCI (Temperature Condition Index) and VCI (Vegetation Condition Index). VCI and TCI are calculated using information of LST and EVI. VHI represents the vegetation state then classified into different drought classes such as no drought, mild, moderate, severe, and extreme [14].

The agricultural sector of East Java played a major role in the economic development of Indonesia [15]. Drought hazard which occurs in East Java will certainly affect agricultural production regionally. Long-term spatiotemporal monitoring of drought in East Java is important for societies and their environment. The advantages of drought monitoring for improving agricultural production, protecting the environment and promoting sustainable socio-economic development [16]. Analysis of agricultural drought in East Java is expected to be used as an early warning of drought and mitigation measures to reduce the impact of drought on agricultural sustainability. This study used VHI indices from Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data. VHI is used for drought mapping and monitoring drought area, especially paddy field area in East Java. This study is essential to determine the probability of occurrence and relationships with climates on different time scales especially in East Java, Indonesia.

2. Data and study area

This study is located in East Java, Indonesia. East Java covers 29 districts and 9 cities. This region located between 111°0' – 114 °4' east longitude and 7 °12 '-8 °48' latitude [17]. Agriculture in East Java centers on rice and corn. Agricultural land covers about 49.4 % of the total area of East Java Province compared to other provinces in Indonesia. The total area of agriculture is about 23,309 km2 which is consists of paddy fields (irrigation and non-irrigation area), plantations, forests, grasslands, fields, unused area, and other lands [17]. The agricultural activity in East java are influenced and controlled by rainfall and availability of water resources in the irrigation system. In normal condition, depending of wet season, the main wet season in Java Island planted between late October and early December. Rice crop harvested between January and March. A smaller dry season planting in April to May and harvested in July to August [18].

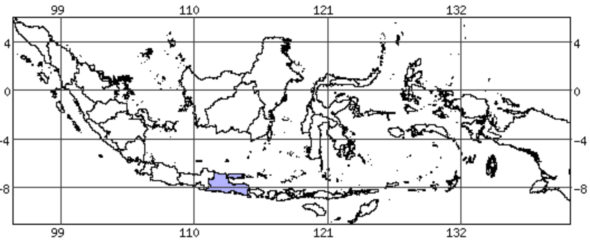

Figure 1. Study area East Java, Indonesia.

In this study, droughts were identified from 1 January 2017 until 31 December 2018. We used Moderate Resolution Imaging Spectroradiometer (MODIS) datasets to calculate remote-sensing-based drought indices. MODIS datasets were obtained from U.S. Geological Survey (USGS). The eight-day 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. Finally, EVI and LST were used to calculate moisture vegetation/vegetation condition (VCI) and temperature condition (TCI), respectively.

3. Methodology

3.1. Vegetation Condition Index (VCI)
Vegetation Condition Index (VCI) was calculated using EVI (Enhanced Vegetation Index) which similar with NDVI but passed through the enhancement. EVI is determined using MODIS red, blue, and near infrared (NIR) band reflectance [19]. Chlorophylls absorb much visible light (380-700 nm) for photosynthesis processes in vegetation with optimum condition. Therefore, reflectance of red light is reduced, and NIR reflectance increases. Low red reflectance indicates high EVI, while high EVI indicates healthy vegetation. Computation of vegetation index need to determine aerosols factor. Aerosol factor can scatter sunlight directly into the optical sensor and increase the red visible light reflectance. Furthermore, aerosol can absorb sunlight and decrease NIR reflectance [20]. In this study we used MODIS product MOD11A3 monthly EVI dataset which has 1 km of spatial resolution. A subsubsection. The paragraph text follows on from the subsubsection heading but should not be in italic. VCI separates the short-term weather related EVI fluctuation from the long-term ecosystem changes [21,22]. VCI can be calculated using following Formula 1 [23]:

$$\mathrm{VCI_i} = 100 \text{ x } \frac{\mathrm{EVI_i - EVI_{min}}}{\mathrm{EVI_{max} - EVI_{min}}} \quad (1)$$

where EVI_i, EVI_{min} and EVI_{max} defined the maximum of eight-day EVI of current month, its multiyear maximum and minimum respectively [24]. VCI has ranges from 0-100 to reflect relative changes in the vegetation condition from extremely bad to optimal [22]. Low VCI indicates a bad condition and high VCI indicates an optimum condition.

3.2. Temperature Condition Index (TCI)
TCI was derived from LST (Land Surface Temperature). We obtained monthly LST from MODIS product MOD11C3 dataset which has 0.050 of spatial resolution. TCI can be calculated using following Formula 2 [23]:

$$\mathrm{TCI_i} = 100 \text{ x } \frac{\mathrm{LST_{max} - LST_i}}{\mathrm{LST_{max} - LST_{min}}} \quad (2)$$

where LST_i, LST_{min} and LST_{max} defined as LST of current month, and maximum and minimum LST value in multi-year. TCI value ranges 0-100. TCI indicated the relation between the actual value of temperature and the temperature that occurred in the potential (LST min) and stress (LST max) crop conditions within the same period [14]. High value of TCI index represents healthy vegetation and low

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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 [14]. In several study, TCI is also produced from brightness temperature.

3.3. Vegetation Health Index (VHI)

VHI represents overall vegetation health, it usually uses for drought mapping. VHI is calculated from VCI and TCI that provides a better comprehension about drought occurrence. Drought mapping using VHI index is better than using only single drought index indicator. VCI can be calculated using following Formula 3 [23]:

$$\mathrm{VHI} = (\mathrm{VCI} + \mathrm{TCI})0.5 \quad (3)$$

Table 1. Classification of VCI, TCI and VHI drought condition.

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

In this study we used monthly LST to get TCI values and monthly EVI to get VCI values. We obtained monthly LST from MOD11C3 MODIS datasets and available at 1000meter spatial resolution. Meanwhile, monthly EVI is derived from MOD13A3 datasets. VCI, TCI, VHI classified into five severity classes, i.e. extreme drought, severe drought, moderate drought, mild drought and no drought [14].

4. Result

The monthly VCI result in 2017 and 2018 shows the differences in vegetation phenology is in 0-100, which follow the theory. The average value can indicate a vegetation phenology or a drought in each season. The monthly VCI analysis results in 2017 as shown in Figure 2, reveal that the maximal average is 54.35 on December, which is rainy season, while the minimal average is 46.31 on August, which is dry season. VCI analysis results in 2018 reveal that the maximal average is 53.72 on January, which is rainy season, while the minimal average is 44.51 on July, which is dry season. The analysis results are shown in Figure 3.

The monthly TCI result in 2017 and 2018 indicated the relation between the actual value of temperature and the temperature that occurred in the potential and stress crop conditions within the same period. As shown in Figure 2, the monthly TCI analysis results in 2017 reveal that the maximal average is 66.29 on January, which is rainy season, while the minimal average is 33.28 on September, which is dry season. TCI analysis results in 2018 reveal that the maximal average is 60.12 on January, which is rainy season, while the minimal average is 28 on October. The analysis results are shown in Figure 3. High value of TCI index represents healthy vegetation and low value of TCI index represents the vegetation stress due to high temperature. Based on average VCI and TCI value in 2017 to 2018 the best condition of vegetations are in December, January, February, and March which is rainy season. Drought occurs in July-November and maximum in October in each year frequently which is dry season.

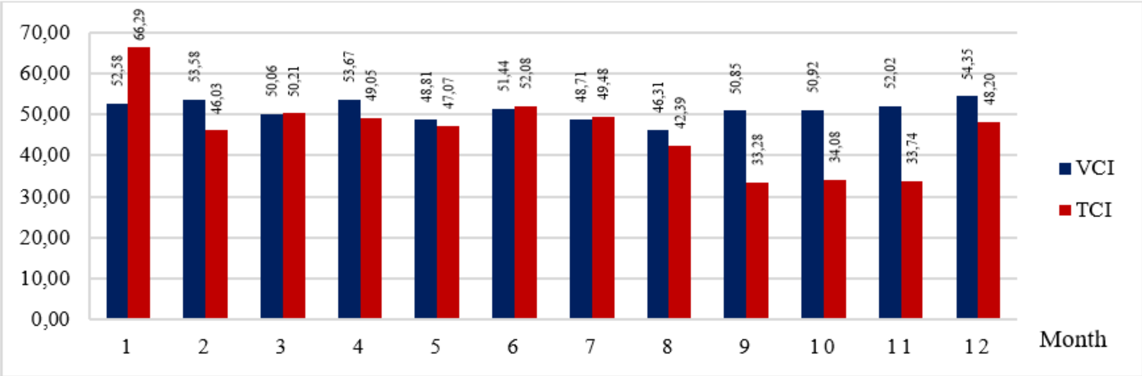


Figure 2. Average monthly VCI and TCI values in 2017.

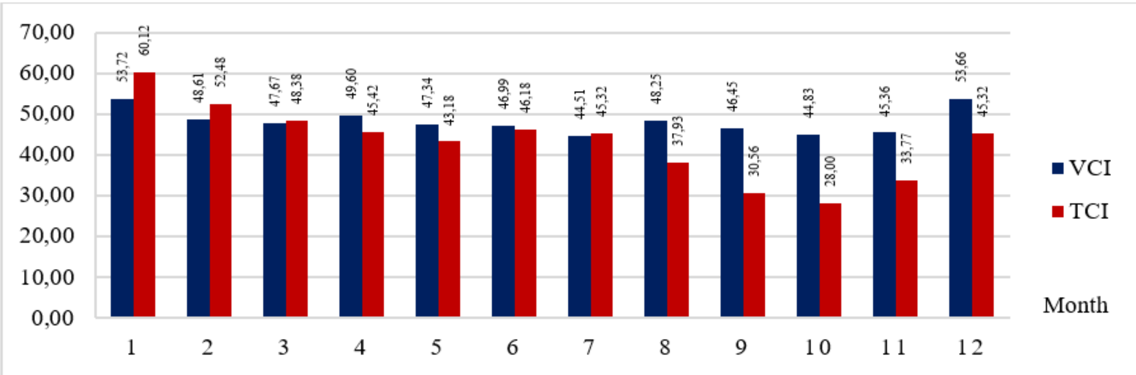


Figure 3. Average monthly VCI and TCI values in 2018.

VHI describes vegetation health from the combination of TCI (temperature) and VCI (vegetation condition) [25]. As shown in Figure 4, 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. The analysis results are shown in Figure 4. The results indicated that average VHI values decreased 13.44 percent, from 42.06 in 2017 to 36.41 in 2018. This figure implied that drought extent in research area has been significant throughout, from mild drought to moderate drought. By comparing VHI with individual VCI and TCI values.

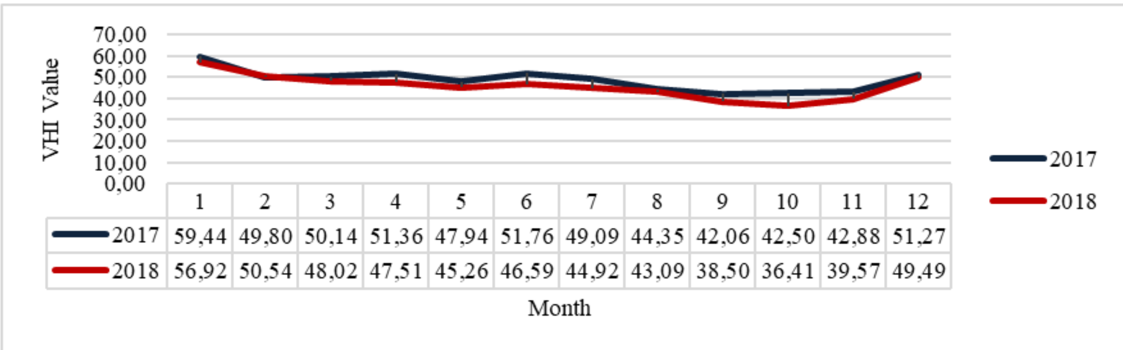
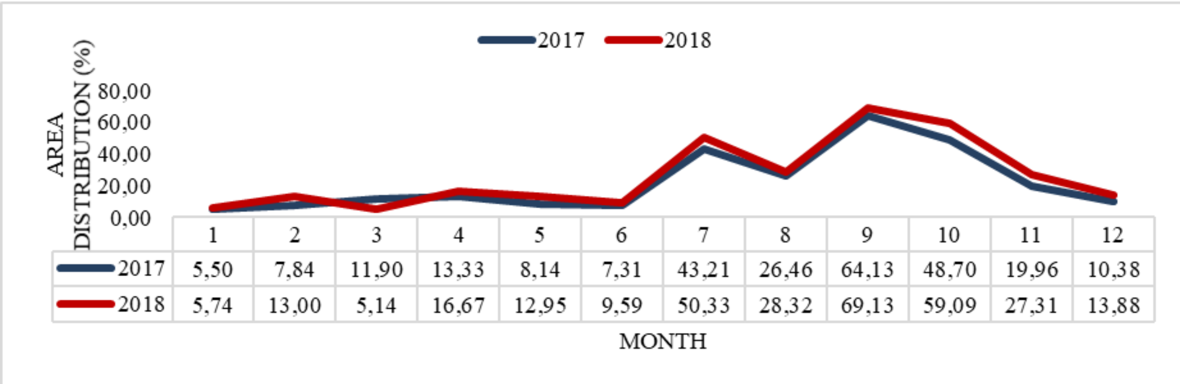


Figure 4. Average monthly VHI values 2017-2018.

As shown in Figure 2 and Figure 3, the result showed that VCI has similar pattern in specific month in 2017 to 2018. The maximal average of VCI on January to February which is rainy season, while the minimal average on July to August which is dry season. Meanwhile, in 2017 to 2018 the result also showed that TCI the maximal average of TCI on January which is rainy season, while the minimal average on September to October which is dry season. Figure 5 show us about percentages of total drought area distribution in East Java, especially in agricultural area that has less than 40 of VHI values. Figure 5, represents about drought area distribution that has severity class of: mild drought, moderate drought, severe drought, and extreme drought area. 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. the drought area extent was range between drought areal extent TCI and VCI, caused by the equal weight of TCI and VCI in VHI calculation. The drought map of TCI, VCI, and VHI were analysed to see any difference or similarity between each index spatially. Based on VHI value in 2017 to 2018 the drought maps in agricultural area of East Java were dominated by moderate drought.



	1	2	3	4	5	6	7	8	9	10	11	12
2017	5,50	7,84	11,90	13,33	8,14	7,31	43,21	26,46	64,13	48,70	19,96	10,38
2018	5,74	13,00	5,14	16,67	12,95	9,59	50,33	28,32	69,13	59,09	27,31	13,88

Figure 5. Drought area distribution (index value 0-40) of VHI in 2017-2018.

5. Conclusion

Drought monitoring using satellite data is really effective to detect the vegetation health spatially and temporary. TCI give better result in detecting severe area when high temperature occurred (dry season). Meanwhile VCI detected drought more sensitive in wet season. Based on VHI values in 2017 to 2018 mostly area in good condition of vegetation except in July to October showed that vegetation stress indicated in some area and covered more than 50% of total agricultural area. Based on VHI monitoring especially in agricultural area in East Java drought area distribution increase 3.69% in period 2017- 2018. Average distribution of drought area is 22.24% in 2017, and 25.93% in 2018 from total wide 1.174,586 km^2 of paddy field area. Based on VHI value in 2017 to 2018 the drought maps in agricultural area of East Java were dominated by moderate drought.

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