Comparison between remote-sensing-based drought indices in East Java

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Abstract. Drought is natural hazard which has causing several impacts, such as decreasing of air and water quality, land degradation, forest fire, decreasing of agricultural crops production. Drought assessment using drought indices have widely conducted for drought monitoring. Remote-sensing-based indices defined as an index which using remote sensing data for mapping the drought condition in particular area or region. This research aims to compare remote-sensing-based drought indices, namely TCI, VCI and VHI to obtain a better understanding about the differentiation between each index, and their application for monitoring drought in East Java on El Nino year 2015. LST and EVI data were used to construct the indices. The result showed, each index proved to be useful, quick, sufficient and inexpensive tool for drought monitoring. However, each index has its differences. TCI proved to be detected drought sensitively in dry season or months when high temperature occurred. While VCI detected drought more sensitive in wet season as well (December-January-February to May) than TCI and VHI. Meanwhile, VHI which the enhancement of TCI and VHI has combined two indicators to provide better comprehension about drought occurrence.

1. Introduction

Drought is natural hazard which frequently occurs in some regions caused by the deficiency of precipitation [1]. Drought has causing several impacts, such as decreasing of air and water quality, land degradation, forest fire, decreasing of agricultural crops production. It may led to water conflict and bring people to immigrate to better place [2][3]. Therefore, drought monitoring is an essential to prevent and minimalize the impact of drought occurrence, Drought monitoring can be assessed by using drought indices. Drought indices defined as a combination of drought indicators (temperature, precipitation, vegetation condition, evapotranspiration, etc.) and provide more comprehensive information for drought analysis than using raw data of each indicators [4].

Niemeyer [5] categorized drought indices into three types, i.e. comprehensive, combined and remote-sensing-based drought indices. Comprehensive drought indices using meteorology, hydrology, and vegetation indicators for describing the drought more widely. PDSI (Palmer Drought Severity Index) is one of comprehensive drought index calculated by using evapotranspiration, runoff, soil recharge, and precipitation indicators. Secondly, combination drought indices is an index combination of two or several drought indices used for drought mapping and monitoring. The example of this

indices are USDM (US Drought Monitoring) which is a combination of several drought index, namely SPI (Standardized Precipitation Index), PDSI, vegetation, and hydrology variable. Moreover, remote sensing based indices defined as an index which using remote sensing data for mapping the drought condition in particular area or region [4].
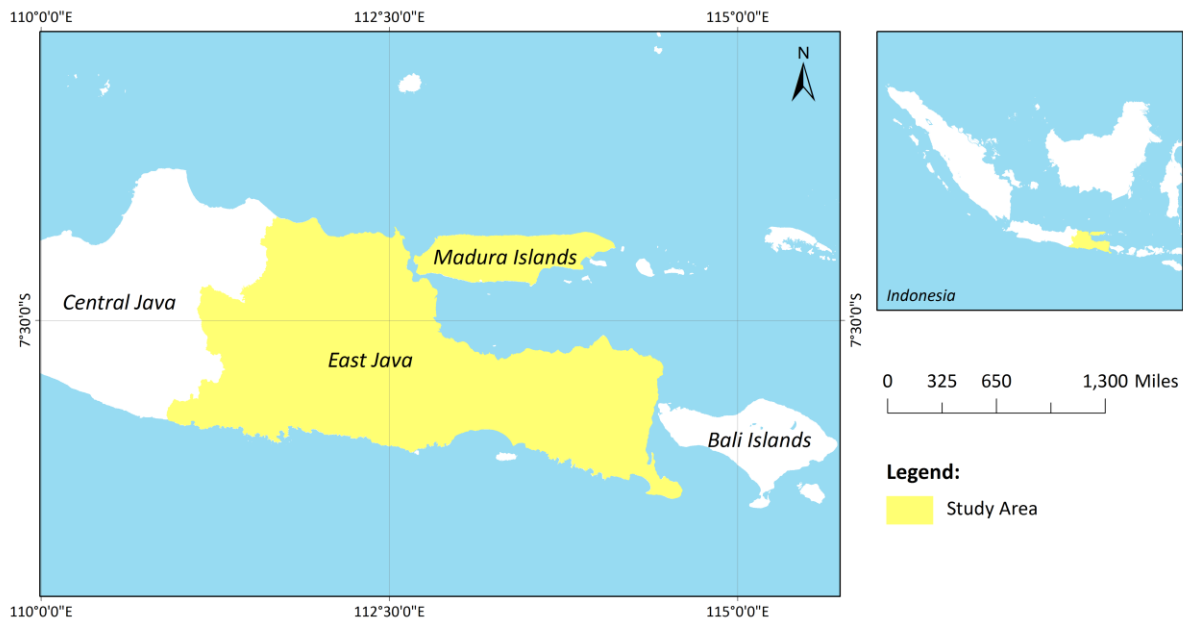

Figure 1. Geographical map of East Java Region

Remote-sensing-based drought indices are widely used because satellite data is more quick, inexpensive, and efficient tools for drought monitoring, than using observational data [1]. There are many remote-sensing-based drought indices which used for drought assessment, e.g. NDVI (Normalized Difference Vegetation Index), TCI (Temperature Condition Index), VCI (Vegetation Condition Index), VHI (Vegetation Condition Index). Beside as drought indices, TCI, VCI, and VHI are classified into vegetation index which describe the condition of vegetation in particular area and categorized them into drought classes, thus they are often to use as indices for drought monitoring [6]. TCI identifies vegetation stress caused by high temperature, as well as excessive wetness [7][8][9]. VCI is commonly used to identify the changes of vegetation from bad to optimum condition [7][8]. VHI describes vegetation health from the combination of TCI (temperature) and VCI (vegetation condition) [8][1].

TCI, VCI, and VHI are remote-sensing-based indices used in this research for drought monitoring in East Java as study area, which one of agricultural production centre in Indonesia [10] is shown in figure 1. Focus period of this research was year of 2015 as strong El Nino event [11]. Thus it may leading to drought occurrence in study area. This research aims to compare these three indices to understand the differentiation between each index, and its application for monitoring drought in East Java on El Nino 2015.

2. Data and Methods
The Moderate Resolution Imaging Spectroradiometer (MODIS) datasets were used to calculate remote-sensing-based drought indices in this research. MODIS datasets were obtained from U.S. Geological Survey (USGS). TCI was derived by using LST (Land Surface Temperature) from MOD11C3 monthly LST with spatial resolution of 0.05°, and calculated by the following equation (equation 1):

$$\text{TCI}_i = \frac{\text{LST}_{max} - \text{LST}_i}{\text{LST}_{max} - \text{LST}_{min}} \times 100 \tag{1}$$

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, while low TCI indicates an unfavourable condition, and high TCI indicates an optimum condition. In several study, TCI is also produced from brightness temperature [1][7][8]. In addition, TCI derived from LST was conducted in several studies, e.g. [12][13].

VCI was constructed by using EVI (Enhanced Vegetation Index) which similar with NDVI but passed through the enhancement. EVI have corrected the aerosol in atmosphere and shadow captured by satellite to reduce the bias that can influenced EVI values [14]. In this study we used MODIS product MOD11A3 monthly EVI with spatial resolution of 1 km. TCI then calculated by the following equation :

$$VCI_i = \frac{EVI_i - EVI_{min}}{EVI_{max} - EVI_{min}} \times 100 \qquad (2)$$

where VCI_i, VCI_{min} and VCI_{max} defined as VCI of current month, and maximum and minimum VCI value in multi-year. VCI also ranges from 0-100, while low VCI indicates an unfavourable condition, and high VCI indicates an optimum condition [1][9].

Lastly, VHI is composed from VCI and TCI provides a better comprehension about drought occurrence, than using only single drought index indicator. The detail of VHI calculation from TCI and VCI illustrated in Figure x (??). VHI calculation also given in following equation:

$$VHI = 0.5VCI + 0.5TCI \qquad (3)$$

TCI, VCI, and VHI then classified into five severity classes (see Table 1).
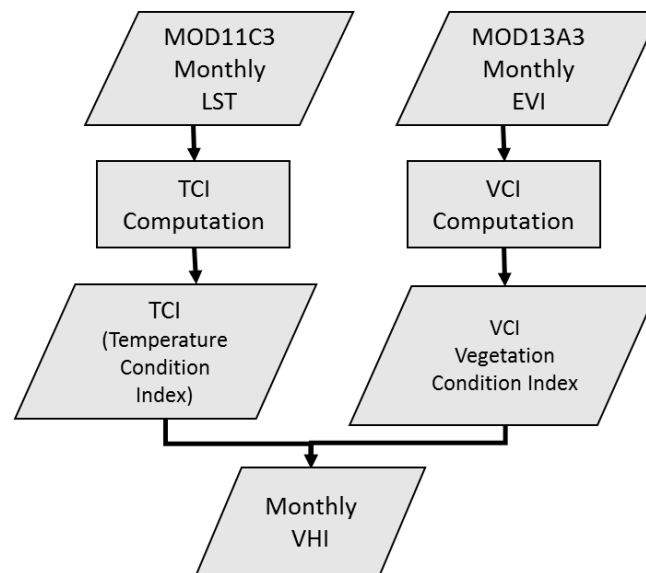

Figure 2. Flow diagram of VHI calculation

Table 1. Drought severity classes for TCI, VCI, and VHI [8][9]

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

3. Result and discussion

The result showed TCI, VCI, and VHI generally has similar pattern from January and December in 2015, which has low areal extent in wet season (December-January-February) and March-April-May shift season from wet season to dry season (figure 3). East Java is influenced by Australian and Asian Monsoon system [15] that has been caused drought occurs in June-July-August and maximum in October in each year frequently [16]. However, result of strong El Nino event in 2015 caused a longer drought duration, which usually end in November, but in 2015 drought was ended in December with areal extent higher than normal year [16].
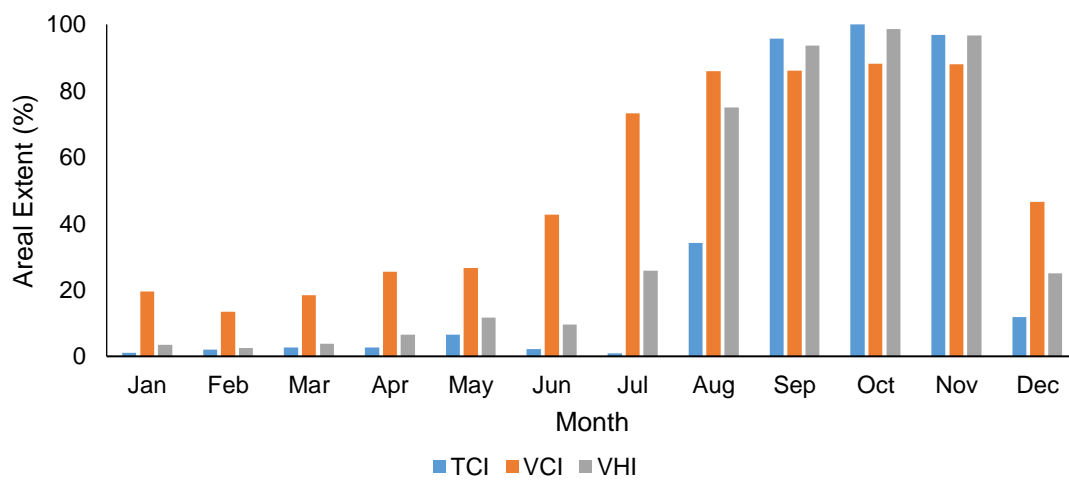

Figure 3. Drought areal extent (index value 0-40) of TCI, VCI, and VHI year 2015

The difference between TCI, VCI, and VHI showed higher areal extent of VCI than TCI and VHI in January to May and December. It clearly seen because areal extent of TCI and VHI were relatively low in those months. It can be due to the indicator used in VCI calculation is vegetation index (EVI) which only consider vegetation condition for monitoring drought. Then, if the harvest season appeared and land became empty, EVI will detect it as drought. Moreover, VCI has high spatial resolution thus it more detail than TCI and VHI.

In contrary, drought areal extent of TCI was tend to high in August to November (dry season). It may be due to indicators used for calculating the index was land surface temperature, which can led to high areal extent of drought if dry season or high temperature occurs. Drought areal extent of VHI also has most similar pattern with VHI (figure 3), however 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. Selected months in 2015, i.e. September, October, and November, were selected to show the drought condition before, during, and after maximum drought in October (Figure 3) El Nino 2015. Figure 4 showed that TCI drought map has similar with VHI drought map in term of spatial, and drought severity classes also similar. The two indices were dominant with moderate and severe drought. In contrast with drought map of VCI which has areal extent of extreme drought in some areas.
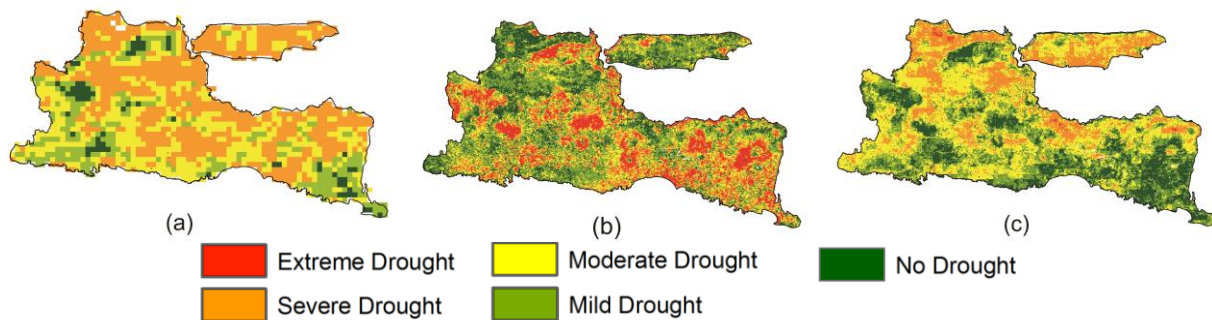
Figure 4. Drought map of September 2015 using (a) TCI, (b) VCI and (c) VHI

While figure 5 showed that TCI, VCI, and VHI drought map were seen similar. Maximum of drought occurrence in East Java is in October [16] which can be seen from Figure 3. The drought maps were dominated by extreme drought in each map. However, TCI has highest areal extent of extreme drought among VCI and VHI. While TCI has the lowest areal extent of extreme drought, and still has no drought areal extent remained in October.
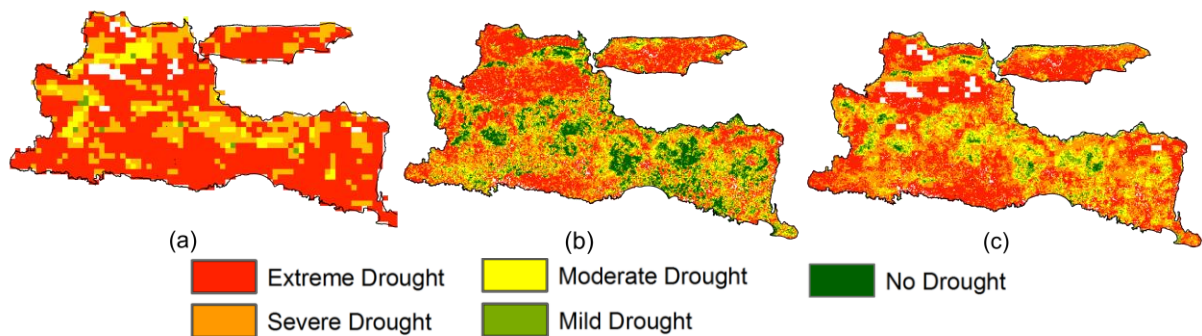

Figure 5. Drought map of October 2015 using (a) TCI, (b) VCI and (c) VHI

While figure 6 showed that TCI, VCI, and VHI drought map were seen also similar. The drought areal extent for three indices has decreased in term of severity. Extreme drought areal extent no longer dominated East Java as in October. In specific area, such as, East area of Madura islands was categorized as extreme drought on each index.
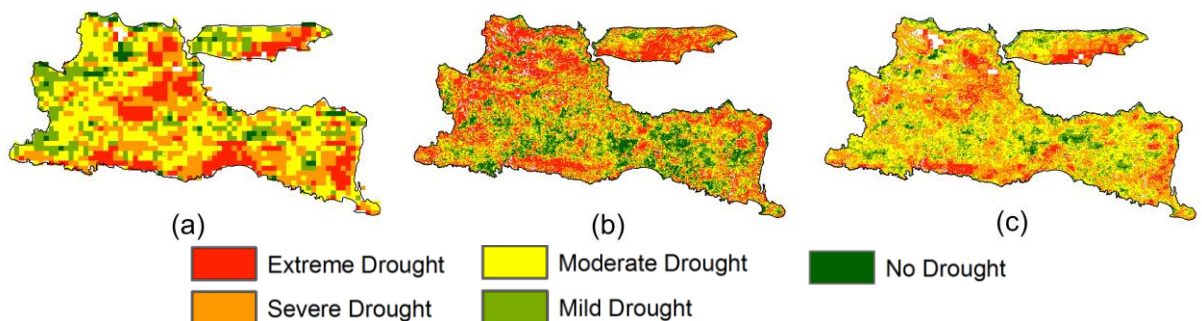

Figure 6. Drought map of October 2015 using (a) TCI, (b) VCI and (c) VHI

Each index proved to be useful, quick, sufficient and inexpensive tool for drought monitoring. However, each index has its differences. For example, in this study, TCI proved to be detected drought sensitively in dry season or months when high temperature occurred. Kogan et al. [8] showed that TCI provides information about vegetation stress caused by high temperature or extensive wetness. While VCI detected drought more sensitive in wet season as well (December-January-February to May) than

TCI and VHI. It may caused by the high resolution of data used for VCI calculation and bias from harvest season thus the index misinterpret unused land after harvest as drought area. But VCI is useful for determine the onset and duration of drought [8] and weather impact on vegetation health [6]. VCI also used for estimating crop productivity [17] because it uses vegetation condition indicator. Meanwhile, VHI which the enhancement of TCI and VHI has combined two indicators, namely temperature and vegetation to provide better comprehension about drought occurrence [8]. The results also showed VHI values were in the middle between TCI and VCI value because of its weight-equal calculation of TCI and VCI to produce VHI.

4. Conclusion

The difference between TCI, VCI, and VHI showed higher areal extent of VCI than TCI and VHI in January to May and December. In contrary, drought areal extent of TCI was tend to high in August to November (dry season). While, drought area extent of VHI was range between drought areal extent TCI and VCI, caused by the equal weight of TCI and VCI in VHI calculation. Each index proved to be useful, quick, sufficient and inexpensive tool for drought monitoring. However, each index has its differences. TCI proved to be detected drought sensitively in dry season or months when high temperature occurred. While VCI detected drought more sensitive in wet season as well (December-January-February to May) than TCI and VHI. Meanwhile, VHI which the enhancement of TCI and VHI has combined two indicators to provide better comprehension about drought occurrence.

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