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Research article

Drought Indices to Map Forest Fire Risks in Topographically Complex Mountain Landscapes

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Abstract.
Drought has the potential to lead to forest fires. Forest fires generally occur during the dry season when the mountain slope forest experiences a water deficit. Drought identification based on remote sensing is useful for mapping potential fires in Arjuno-Welirang Forest and TNBTS Forest (in Bromo Tengger Semeru National Park). This research used Landsat-8 images in 118/065 and 118/066 in August and November 2015-2018. Validation data were obtained using high resolution planet scope images and rainfall data. Three drought indices were tested to identify fires, namely TVDI, VHI and NDDI. The indices were tested visually using high resolution images and tested meteorologically using SPI. From the results of the accuracy test and correlation, TVDI had the highest accuracy in the Arjuno-Welirang forest (96% accurate), while the best index for TNBTS was the VHI index (96% accurate).

Keywords: drought indices, TVDI, VHI, NDDI, forest fires, Indonesia

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1. Introduction

Drought is a decrease in rainfall in a certain season or period which can lead to reduced water resources to meet human and environmental needs. Meteorological drought includes natural events where rainfall decreases below normal in certain periods. Drought is hydrologically defined as reduced discharge from streams, reservoirs or lakes, the supply of groundwater. Drought has an impact on reduced crop production due to lack of water, this is caused by reduced soil moisture [1]. Drought impacts to plants include the inferences of growth in all types of vegetation from dry land agriculture, wetland agriculture, as well as forests. Drought and water shortages have a direct impact on plant activity, the main component of the plant body is water, which at the same time has a main function as a raw material for the photosynthesis process, the

preparation of protoplasm, and maintaining the cell turgol used for the transpiration process [2].

Drought has the potential to cause forest fires. Forest fires generally occur during the dry season where forests on mountain slopes experience a water deficit so that several types of plants in the forest wither as part of the adaptation process, dry tree litter has a high probability of burning if exposed to sparks even in large quantities. a little bit. The cause of forest fires in Indonesia is caused by human behavior, both intentional and unintentional, and comes from natural factors in the form of volcanic eruptions, lightning, coal and others [1].

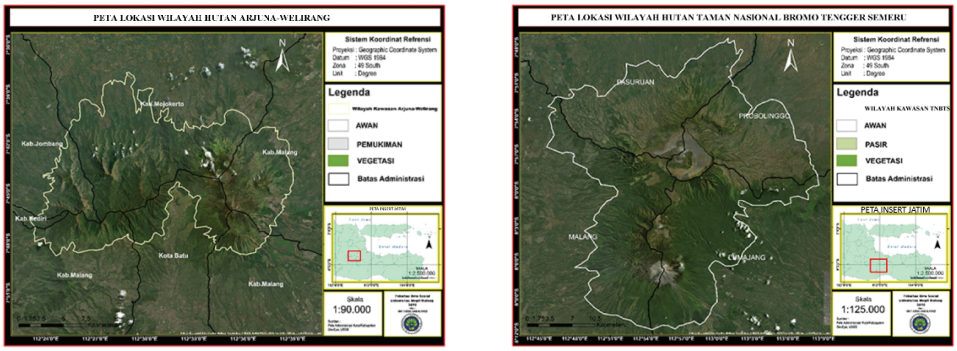
East Java Disaster Management Agency BPBD data shows that forest fires occurred in TNBTS and Arjuno-Welirang from 2014 to 2018 were 79 events. Forest fires were dominated in the administrative area of Mojokerto Regency with as many as 51 incidents, Batu City 4 incidents in the Arjuno-Welirang area. In Malang Regency, it has 4 incidents, Pasuruan Regency has 2 incidents, Probolinggo Regency has 5 incidents and Lumajang Regency has 9 incidents in TNBTS area [4]. The research location in the Arjuno-Welirang Mountains and Bromo Tengger Semeru National Park, which is an active mountain, Mount Arjuna-Welirang until now has a level as a level 1 volcano, while Mount Bromo and Mount Semeru are volcanoes level 2 so that forest fires triggered by volcanic activity has a high potential [5].

The development of increasingly sophisticated technology makes it easier for researchers to obtain data, one of the data that can be used and accessed by the public is downloadable satellite images that continue to monitor the earth in relation to the dynamics of changes in soil, water, and vegetation on the earth's surface. [6]. The drought index was used to determine the level of forest dryness in the Arjuna area and the Bromo Tengger Semeru National Park (TNBTS) area, which is further related to the potential for forest fires in the area. The spectral index was used to identify the dryness in the study area [7]. Given the importance of accurate forest monitoring tools, it is then essential to examine the performance of varying available drought indices to map forest fires in Indonesia. Based on this background, the objectives of this research are 1) Identify the performance of Temperature Vegetation Dryness Index (TVDI), Normalized Difference Water Index (NDWI) and Vegetation Health Index (VHI) to obtain a visual drought index; 2) Compare and assess the Temperature Vegetation Dryness Index (TVDI), Normalized Difference Water Index (NDWI) and Vegetation Health Index (VHI) to obtain a meteorologically suitable index.

2. Method

2.1. Study Area

The location of the research are 2 mountainous complexes, namely the Arjuno-Welirang forest area and the Bromo Tengger Semeru National Park (TNBTS). The Arjuna area is situated in several administrative areas: Batu City, Mojokerto Regency, Pasuruan Regency, Malang Regency, Kediri Regency and Jombang Regency. The TNBTS area is located in Malang Regency, Pasuruan Regency, Lumajang Regency and Probolinggo Regency. These two areas are located quite close together with a distance of about 32 km.



(a) (b)

Figure 1: (a) Arjuna Welirang and (b) Taman Nasional Bromo Tengger Semeru.

2.2. Comparison of Temperature Vegetation Dryness Index (TVDI), Normalized Difference Water Index (NDWI) and Vegetation Health Index (VHI) to obtain the dryness index visually.

This stage utilized Landsat 8 OLI/TIRS Image from 2015 – 2018. The forest fire events for 2015-2018 were collected from BPDP. Image processing was done by combining 2 images, namely patch/row 118/065 and 118/066 because the study area is wide. The scenes were corrected for Top of Atmosphere (TOA). Correction of atmosphere was done using the FLAASH model and Cloud masking. The 2 images were in the same month, as it is assumed that in the same month they have the same data results. The image that has the smallest cloud cover is used as the base image and the next image as the cover. Table 1 shows the indices in numerical equations.

The indices used for this research are the Temperature Vegetation Dryness Index (TVDI) [8], Vegetation Health Index (VHI) [9], and Normalized Difference Drought Index (NDDI) [6]. The index is derived from the Normalized Difference Vegetation Index

(NDVI), Normalized Difference Water Index (NDWI), Land Surface Temperature (LST) derivatives. The results of the three indices were compared with the actual situation and the incidence of forest fires in the research area, so that it can be seen which index is more appropriate to apply. The NDDI index is the latest model in mapping drought using remote sensing, NDDI has the advantage of identifying droughts on a large area scale [10] by considering vegetation density parameters and wetness parameters [11].

Table 1: Indices used in this study.

Equation	Source
$TVDI = \frac{Ts - TSmin}{Tsmax - tsmin}$ (2.1) where , TVDI : *Temperature Vegetation Dryness Index*, Ts_{min} : Temperature at surface on triangle defining the wet section, NDVI : Observed NDVI, Ts_{max}: Maxim temperature at every NDVI : (Ts_{max}= a+b NDVI)	[8]
$VHI = aVCI + (1 - a) * TCI$ (2.2) VHI : *Vegetation Health Index,* VCI : *Vegetation Condition Index,* TCI : *Temperature Condition Index,* α : weight from VCI (humidity) and TCI temperature to leafs condition (0,5)	[9]
$NDDI = \frac{NDVI - NDWI}{NDVI + NDWI}$ (2.3) NDDI : *Normalization Difference Drought index,* NDVI: *Normalised Difference Vegetation Index,* NDWI: *Normalized Difference Water Index*	[10]

This drought identification variable was analyzed using three indices to find the most suitable level of accuracy for the Arjuno-Welirang forest and Bromo Tengger Semeru National Park (TNBTS). Assessment was made visually using a planet scope. The results of the index identification will be classified to determine the classification of the level of drought, where they can be seen in Tables 2 – 4 below.

Table 2: Drought classes of TVDI.

Drought level	TVDI
Wet	0 <TVDI ≤0,2
Moderately wet	0,2 < TVDI ≤ 0,4
Normal	0,4 < TVDI ≤ 0,6
Moderately dry	0,6 < TVDI ≤ 0,8
Dry	0,8 < TVDI ≤ 1

Source: [9]

Table 3: Drought classes of VHI.

VHI value	Drought level
< 10	(Extreme Drought)
< 20	(*Severe Drought*)
< 30	(*Moderate Drought*)
< 40	(*Mild Drought*)
>40	(*No Drought*)

Source : [10]

Table 4: Drought classes of NDDI.

NDDI	Drought level
>-0,05 – 0,01	Extreme drought
0,01- 0,15	Moderate drought
0,15-0,25	Mild drought
0,25-1	normal
>1	No drought

2.3. Comparison of Temperature Vegetation Dryness Index (TVDI), Normalized Difference Water Index (NDWI) and Vegetation Health Index (VHI) to obtain a meteorologically suitable index

The variable for validation uses meteorological drought identification, namely the Standardized Precipitation Index (SPI). This is to test the accuracy of the drought index based on remote sensing data. SPI index processing can be done using the formula (2.4) as follows [12].

$$G(x) = \int_0^x g(x) = (1)/(\beta^a T(a) \int_0^x t^{a-1}\ e^{-x/\beta} dx. (2.4)$$

Where , A>0 : shape parameter, B>0 : parameter, x>0 : Amount of rain, value α and β are estimates for each rain stations.

The value of the SPI index were from the transformation of the gamma distribution G(x) into standard normal with an average value of 0 and the difference has a value of 1 as in the formula (2.5)

Z = SPI = $-(t - \frac{c_0+c_1+c_2t^2}{1+d_1+d_2+d_3t^2})$ for 0 < H (x) ≤ 1,0 (2.5)

where :

$t = \sqrt{ln\ (1/(H\ (x))^2}$ for 0< H(x) ≤ 0

$t = \sqrt{ln\ (1/(1,0 - H\ (x))\ 2}$ for 0,5 < H(x) ≤ 0

With coefficients fo=rom Mc.Kee as below :

c0= 2,515517 d1 = 1,432788

c1 = 0,802853 d2 = 0,189269

c2 = 0,010328 d3 = 0,001308

The results of processing the VHI, NDDI and TVDI were correlated with the SPI index. The value of the correlation (r) ranges from -1 to +1 the criteria are as in the table below, a value of 0 indicates that the values between these variables are not correlated, if -1 the correlation value is perfect but negative as well as +1 the perfect correlation value is positive.

Table 5: Degree of correlation values.

r	Interpretation
0-0,199	Very low
0,2-0,399	Low
0,4-0,599	Moderate
0,6-0,799	Strong
0,8-1	Very strong

Source: [13]

The results of the rainfall and temperature tests were compared with data of fire events in the field. The dates and events were adjusted to the spatial temporal from satellite imagery so that the day when the fire occurs can be directly tested.

Table 6: Decision matrix.

No	Record dates	Normal	Mild drought	Moderate drought	Severe drought	VEry extreme drought	Total events
1	-	-	-	-	-	-	0
2	-	-	-	-	-	-	0
3	-	-	-	-	-	-	0
Total		0	0	0	1	3	0
percentage accuracy		0%	0%	0%	0%	0%	

3. Result and Discussion

3.1. Visual assessment of three indices

The images were taken in August in 2015-2018 to minimize clouds, as shown in Figure 2 shows drought visually in the Arjuno-Welirang area.

Each of the indices has a different visual. On the TVDI index, the result of the pixel value is dominant yellow at the peak between Welirang Arjuna and orange at the peak of Welirang. On the west side slope shows the area has normal conditions, so the TDVI is considered suitable with the conditions there. For VHI index, the results of the pixel value have a color dominated by green so that at that location all of them have normal to wet conditions, the crater at Welirang is considered normal, there is no drought. This leads to a condition where the VHI index is less appropriate. The NDDI index shows the location recorded by the PlanetScope image has a dominant red color indicating the class is very dry, which was also not suitable and different from Planet Scope images.

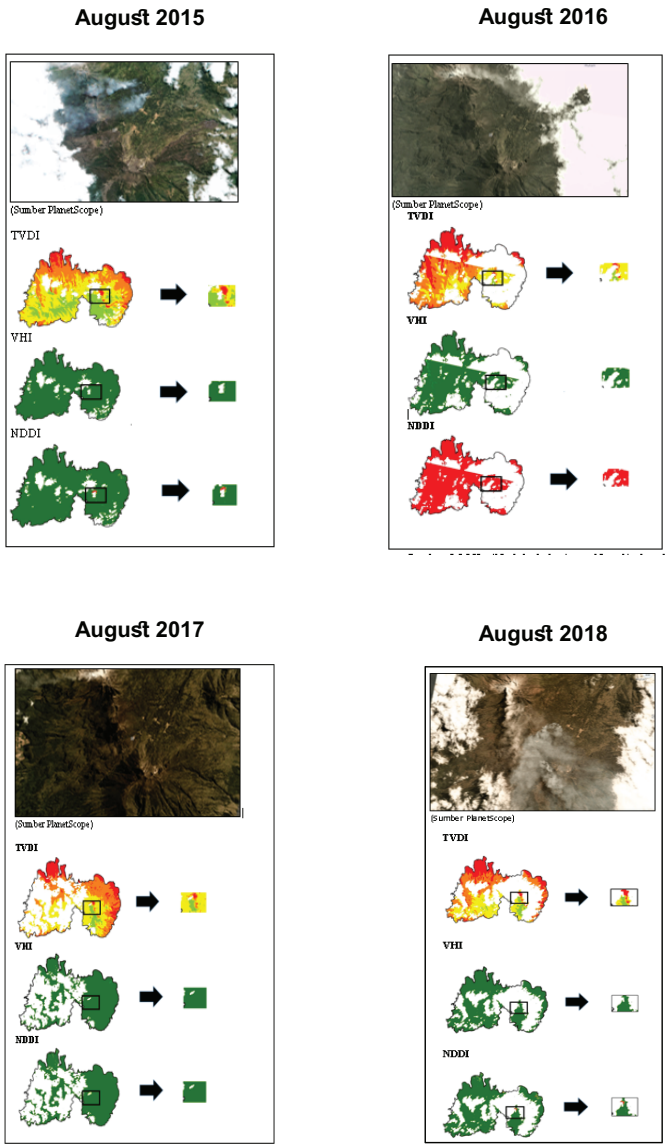


Figure 2: Comparison of pixel values between TVDI, VHI and NDDI indices in Arjuna-Welirang.

The highest total score was obtained by the TVDI index with a total score of 25 with a percentage of 96%. The TVDI index has a high level of accuracy in the Arjuno-Welirang location. In contrast to VHI, which only has a total score of 10, and NDDI of 11 with a percentage of 30% and 34% respectively. Visually, the TVDI Index is more accurate and consistent in presenting each pixel and the occurrence of fires as well as visual conditions in the area of the peaks of Mount Arjuna and Welirang. Similar to the interpretation of Arjuno-Welirang, for the TNBTS area monitoring was carried out in August 2015-2018 as shown in Figure 3 below.

For the TVDI index, the pixel colors were dominated by red and yellow, the red color was on the inside of Bromo and the yellow color was the slope of Bromo. The red color showed the same location as the burnt area, making the TVDI index visually

Table 7: Decision for comparing the indices in Arjuno-Welirang.

No	Record dates	TVDI	VHI	NDDI
1	August 2018	3	2	1
2	September 2018	3	1	1
3	September 2018	3	1	1
4	August 2014	2	1	3
5	August 2015	3	0	0
6	August 2016	3	1	1
7	August 2017	3	2	2
8	August 2018	3	0	0
Total		23	8	9
percentage accuracy		96%	30%	34%

Decision for comparing the indices in Arjuno-Welirang

appropriate. For the VHI Index, the results from PlanetScope image showed that the location was orange to yellow at the location of the fire incident, and the surrounding area was dominated by green pixels which indicate the area is normal, so this was also appropriate. In the NDDI, the location showed the dominance of light green and yellow pixel colors in the burned area, where the light green color was included in the normal classification, and the yellow color indicates low dryness. For the sensitivity level, the NDDI index was less suitable as it only detected mild dryness.

Table 8: Decision for visual comparison of three indices in TNBTS.

No	Record dates	TVDI	VHI	NDDI
1	September 2017	3	3	1
2	September 2018	3	3	0
3	October 2015	3	2	2
4	September 2014	0	3	3
5	August 2015	2	3	1
6	August 2016	2	3	3
7	August 2017	3	3	0
8	August 2018	3	3	0
Total		19	23	10
percentage accuracy		79%	96%	41%

* Score:0 = Not suitable1 = less suitable, 2 = suitable, 3 =very suitable

The results of the accuracy test in TNBTS which were ana;yized using the same method as in Arjuno-Welirang. The results showed that the VHI index is the highest with a percentage of 96%, thus the VHI index is more suitable for identifying drought in the TNBTS area. TVDI has an accuracy rate of 79%, this value is high enough for accuracy in identifying dry and burnt areas so that the TVDI index can be an alternative.

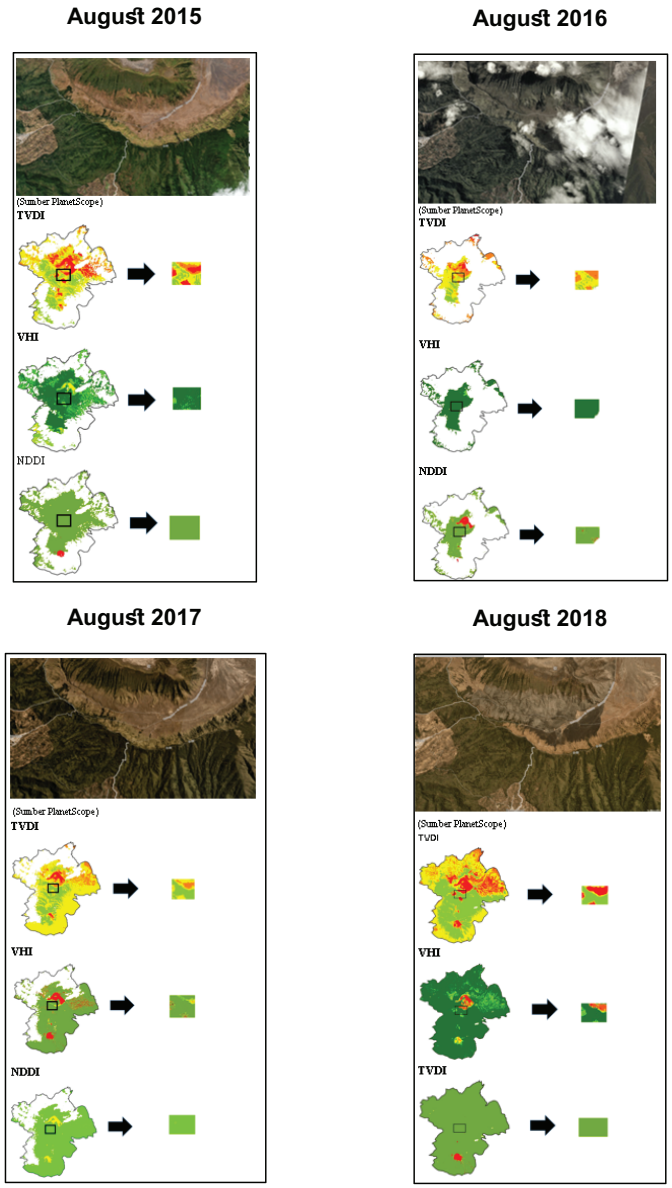


Figure 3: Visual comparison of three indices TVDI,VHI and NDDI ini TNBTS.

The NDDI index has the lowest accuracy rate, which was only 41% because the NDDI index is less sensitive in identifying droughts and forest fires so that the NDDI index is considered not suitable.

3.2. Comparison of the Temperature Vegetation Dryness Index (TVDI), Normalized Difference Water Index (NDWI) and Vegetation Health Index (VHI) to obtain a meteorologically suitable index

The next accuracy test was using the SPI index, which is a climatology-based drought index. The SPI was calculated on a monthly basis. The value of r is that there is a Pearson correlation between -1 to 1, meaning that the closer the value is to 0 then the correlation level is getting weaker, the meaning of -1 is the perfect negative correlation and the meaning of 1 is the perfect positive correlation. The r does not have a unit sign + and – is the direction of the relationship [3], if the data is in a linear line it shows the stronger the correlation between these variables [3]. The correlation between SPI and drought index using remote sensing in the Arjuno-Welirang and TNBTS areas can be seen in Tables 9 and 10.

Table 9: Pearson correlation in Arjuno-Welirang.

No	Drought index	Correlation
1	TVDI	-0,915
2	VHI	0,81
3	NDDI	0,459

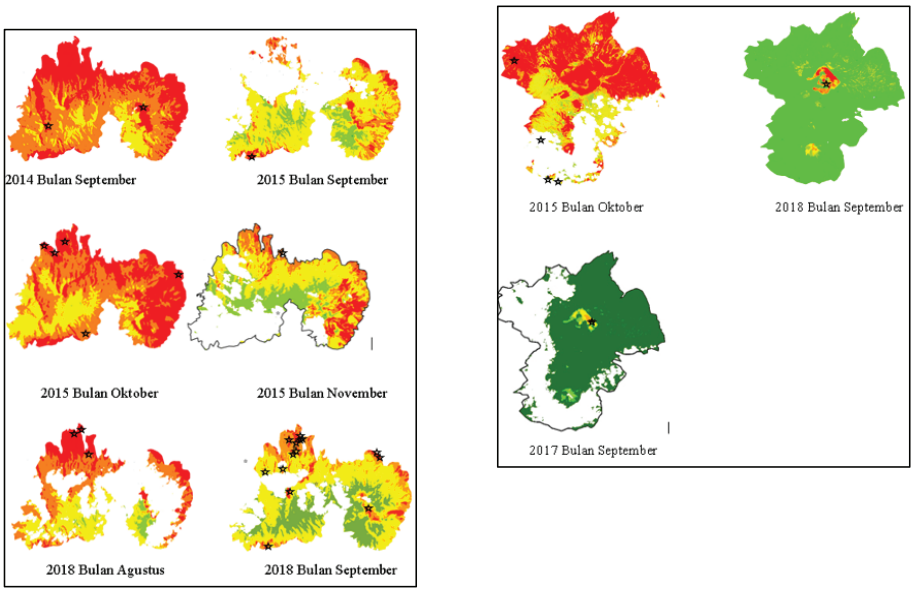
Table 9 shows the index that has a significant relationship between the SPI index and the remote sensing-based Drought Index. The results of statistical tests show that the relationship between the SPI index and TVDI has a relationship with a value of -0.915, which is very strong negatively. The results of the correlation statistics show a correlation level of 0.81 which shows the SPI index with VHI has a very strong correlation level. The data entered was 84 samples. The results showed that the relationship between the SPI index and NDDI has a relationship with a value of 0.46 which indicates a moderate level of correlation.

Table 10: Pearson correlation at TNBTS.

No	Drought Index	Correlation
1	TVDI	-0.673
2	VHI	0.884
3	NDDI	0.556

The results from table 10 show the correlation of the drought index with the meteorological-based drought index in TNBTS. The TVDI index has an r of -0.673 while for VHI and SPI are 0.884 and 0.566. The results of the visual test and the correlation can be concluded that for the Arjuno-Welirang, the TVDI index has the highest accuracy

level and is suitable for the Arjuno-Welirang forest area, with a sensitivity level of dry to wet areas making it suitable for that area. Based on this, the TVDI index could be used as a guide and analysis to identify potential forest fire areas in the Arjuno-Welirang area. The TDVI and VHI indices were then tested for spatio-temporal variability as shown in Figure 4 below.



(1) (2)

Figure 4: Comparing the best index (1) TDVI at Arjuno-Welirang (2) VHI at TNBTS.

Based on the TVDI index for the Arjuno-Welirang location and the VHI index for TNBTS areas, the areas were covered by dry classes with a potential for fire, along with slightly dry class areas, in all recorded images from 2014 to 2018. The results were areas with fire potential and no fire potential. Then, for the months of June, July and August, there are areas affected by fires and the index value was classified as dry class, so it was included in the potential fire area after one month of the dry season. To test the index of both can be seen in the following table 3.5-3.6.

The results of the comparison with East Java BPBD fires events data can be seen from Table 11. The dominance of the burned area was in the dry class with a percentage of 74.07%, slightly dry 22.2% and normal is 3.7%. The data from BPBD according to the researcher is incomplete, because there are several burnt areas that are not recorded, as can be seen from the visual accuracy test in August 2015, which were not found in the BPBD.

Table 12 shows the drought class on the VHI index with fire incident data from BPBD data. It was only 4 events, because other events in the TNBTS area have intensive cloud

Table 11: Accuracy results from TVDI with forest fire events ini Arjuno-Welirang.

No	Acquisition Date	Wet	Moderate Wet	Normal	Moderate Dry	Dry	Total Events
1	September 2014	-	-	-	-	2	2
2	September 2015	-	-	-	-	1	1
3	october 2015	-	-	-	1	4	5
4	November 2015	-	-	-	1	-	1
5	August 2018	-	-	-	-	3	3
6	August 2016	-	-	1	4	10	15
Total		0	0	1	6	20	27
percentage accuracy		0%	0%	3,7%	22,2%	74,07%	

Table 12: VHI Index Class Accuracy Test with Forest Fire Incidence in TNBTS.

No	Acquisition Date	Normal	Low Drought	Moderate Drought	Drought	Severe Drought	Total Events
1	Oktober 2015	-	-	-	-	2	2
2	September 2018	-	-	-	-	1	1
3	September 2017	-	-	-	1	-	1
Total		0	0	0	1	3	4
percentage accuracy		0%	0%	0%	25%	75%	

cover so only 4 events can be tested. In very heavy dry class, the percentage of fire incidence is 75% and dry weight is 25%, so the accuracy of fire potential is in very heavy dry class.

4. Conclusion

Accuracy of drought indices in Arjuno-Welirang showed that TDV is the most suitable with an accuracy of 96% on the TVDI while only 30% for VHI index and 34% for NDDI index. While in TNBTS, the accuracy of the TVDI index is 79%, while VHI is 96% and the NDDI index is 41%. The differing accuracy levels in two mountanoeus complexes suggests that local biophysical conditions affect the remote sensing reflectance and thus the indices. The correlation test with the SPI index for the Arjuno-Welirang forest for TVDI index is -0.95 while VHI index has a value of 0.81 and the NDDI index value has a value of 0.459. This suggests that TDVI has the best ability to differentiate climatic variability. On the other hand, the correlation test in TNBTS forest for TVDI index is -0.673 while VHI index has a value of 0.884 and the NDDI index has a value of 0.566. The VHI apparently became the most suitable drought index in TNBTS. Further research is needed to understand what mechanism drives the differences of accuracy in these two regions.

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