DROUGHT MONITORING OVER PADDY FIELD AREA IN INDRAMAYU DISTRICT WEST JAVA USING REMOTELY SENSED INDICES

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ATcv words: *Agricultural drought. Meteorological drought, Standardized Precipitation Index, Temperature Condition Index, Vegetation Condition Index.*

Introduction

Drought occurs when there is a lack of water in particular area and usually caused by reduced amount of rainfall over that particular area. In Indonesia, the impact of drought is usually noticed in the agricultural land. Monitoring agricultural drought is mostly done based on field information of rainfall, crop condi(ion,water availability, etc. Earth observations from satellites are used to be the complementary to those collected by *in-situ* systems. Remote sensing satellites are often necessary for the provision of synoptic, wide-area coverage and frequent information required for spatial monitoringof drought conditions.

In the present state, remotely sensed data are commonly used for rainfall, surface wetness, temperature and vegetation monitoring. Many researches have been developed some agricultural drought indices usinu remote sensing data (Kogan, 1990, 2002; Sandholt <?/tf/., 2002; Xin *e/al,* 2003). One of the agricultural drought indices is based on the estimation of vegetation stress, called as VHI developed by Kogan (1990). It was designed to monitor vegetation health based on its moisture, and thermal conditions. VHI is found to be more effective compared to other indices in monitoring the agricultural drought (Kogan. 1990, 1995, 1997, 2001; Singh *el al,* 2003). This method have been applied successfully in many countries such as USA, Kazakhstan/Israel. Poland, Africa. Argentina, Mongolia, China, and India (Kogan. 1998;*}\eiai* 2003;Martyniak».•/«/., 2004; Unganai *el al,* 1998; Seiler, 2000; Kogan *el al,* 2004; Xin *el al,* 2003; Wang *el al,* 2001; Bhuiyan, 2004; Bhuiyan *el al,* 2006).

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So far. the VHI method has been only applied using Nalional Oceanic and Atmospheric Administration - Advanced Very High Resolution Radiometer (NOAA-AVHRR) data because of their long archives from 1981. However, AVHRR is a broadband remote sensor designed primarily to look at snow and atmosphere properties (clouds), not vegetation (NASA Goddard Space Flight Center, 2001). Nowadays, there are some satellite sensors in orbit that arc much better calibrated than AVHRR and specifically designed to measure the Earth's vegetation. The satellite based vegetation monitoring plays an important role in drought monitoring and early warning, because the vegetation condition reflects the overall effects of rainfall, soil moisture, and agricultural practice. The MODIS flying aboard Terra/Aqua since 1999 has a good capability in spectral, revisiting, and spatial resolution for vegetation monitoring. Therefore, an application of Kogan's method using MODIS data could provide a better drought information.

The objective of this paper is to develop the meteorological and agricultural drought mdiccs over paddy area in Java Island.. Those indices are SPI, Vegetation Condition Index (VCI). Temperature Condition Index (TCI), and VHI.

1 SPI

SPI was proposed by McKee *et ah* (1993) to assess anomalous and extreme precipitation. Since precipitation data are noslly skewed, in order to compute SPI, precipitation data are normalized using the jamma function. The SPI is based on the probability of precipitation for any desired time scale and spatially invariant indicator of drought (Guttman, 1998, 1999). The SPI is computed by dividing the difference between the normalized seasonal precipitation and its long-term seasonal mean by the standard deviation. Therefore, the formula of SPI could be written as

$$SPI = \frac{Xij - \overline{X}}{\sigma} \quad (1)$$

where, Xjj is the seasonal precipitation at the i[1"] raingauge station and j observation, X is the long-term seasonal mean and o is its standard deviation. The negative index is for drought and positive index for non-drought conditions.

3. VHI

VHI is calculated from Normalized Difference Vegetation Index (NDVI) and Brightness Temperature (BT) or Land Surface Temperature (LST) values using the following algorithms: (a) the removal of temporal high frequency noise (clouds, sun and sensor angular effects, etc) from annual time series; (b) the calculation of climatology from many years of data; and (c) the estimation of medium-to-low frequency fluctuations of NDVI and LST (departure from climatology) associated with weather variations. The products consist of three indices, i.e. NDVI-based VCI. LST-based Temperature TCI and VHI which the associated formulas arc written as follows

$$NDVI = (NIR - VIS) / (NIR + VIS) \quad (2)$$

$$VCI = 100 * (NDVI - NDVI_{min}) / (NDVI_{max} - NDVI_{min}) \quad (3)$$

$$TCI = 100 * (LST_{max} - LST) / (LST_{max} - LST_{min}) \quad (4)$$

$$VHI = a * VCI + b * TCI \quad (5)$$

where NDVI, $NDVI_{max}$ and $NDVI_{min}$ (LST, LST_{max} and LST_{min}) are the 10-day NDVI (LST), absolute multi-year maximum NDVI (LST), and absolute multi-year minimum NDVI (LST), respectively; a and b are coefficients quantifying a share of

VCI and TCI contribution in the Vffl. Based on the previous study, these coefficients are assumed to be equal (i. e.. a=b = 0.5).

Drought of vegetation is closely related with weather. In NDVI, the strong ecological component subdues the water component. On the other hand, VCI separates the short-term weather-related NDVI fluctuations from the long-term ecosystem changes. Therefore, while NDVI shows seasonal vegetation dynamics, VCI varies in the range of 0 and 100% which reflects relative changes in the vegetation condition from extremely bad to optimal (Kogan *era!.*, 2004).

Higher VCI values correspond well with the favorable moisture condition and represent the unstressed vegetation. VCI not only identifies drought, but also numerically estimates of its intensity, duration, dynamics, and impacts on agriculture. VCI can be used independently to identify drought areas and the consequences of drought. The VCI can also be used as a supplemental source of information covering the areas when the meteorological data are not available or not complete to characterize the detail weather impacts over space and time (Kogan, 1990). Meanwhile, low TCI values correspond to vegetation stress due to dryness of high temperatures. TCI provides opportunity to identify the subtle change in vegetation health due to the thermal effects as drought proliferates if the moisture shortage is accompanied by high temperatures. For calculating VHI, an equal weight has been assumed and assigned to both VCI and TCI, since moisture and temperature contribution during a vegetation cycle are currently not known (Kogan, 2001).

Principally, VCI and TCI assess a particular year of the NDVI and LST dynamics relative to the range of their variation during extreme (stressed to favorable) conditions. The thresholds for the extreme conditions are derived by calculating the maximum and minimum NDVI and LST values from multi-year satellite sensor data for each land pixel and each period (weekly or ten days). VCI, TCI and VHI characterize moisture, thermal and vegetation health conditions, respectively.

4. Material and Method

4.1. Data

There are four data sets are used in this research: (a) Daily MOD1S LIB from 2003 - 2006 during the dry season from May to September, (b) Monthly rainfall data derived from the NOAA satellite based on OLR data from 1980 to 2005 in Indramayu region (c) Paddy area derived from the landuse classification from Landsat-7 ETM+ 2003, and (d) Soil moisture data from field survey (July 2004, July and September 2005).

4.2. Study Area

Indramayu has been known as one of the central paddy production areas in the West Java Province - Indonesia. However, it was recorded by Indramayu District Office of Department of Agriculture that the agricultural sector in Indramayu is quite responsive to the climate anomaly, such us FJ Nino and La Nina. The probability of the drought occurrence in Indramayu could be above 60% and the area effected by drought could cover 30,000 ha (Boer *el ai.* 2003). The paddy field area in Indramayu District can be seen in Figure I.

It was reported that the drought happened in Indramayu during July until August 2003. The drought acreage reached until 55,250 ha in Indramayu. The severe drought was found along the north pan of Indramayu (Indramayu District Office of Department of Agriculture, 2003). Meanwhile, the high intensity of I drought In Indramayu was recorded as 1.815 I ha in the end of June 2004 with the total of I drought acreage 3,047 ha. The drought I eventually occurs in the municipal of Arahan, I Karangampel, Kandanghaur, Losarang, I Krangkeng, Juntinyuat and Lohbenerl (Indramayu District Office of Department of I Agriculture, 2004).

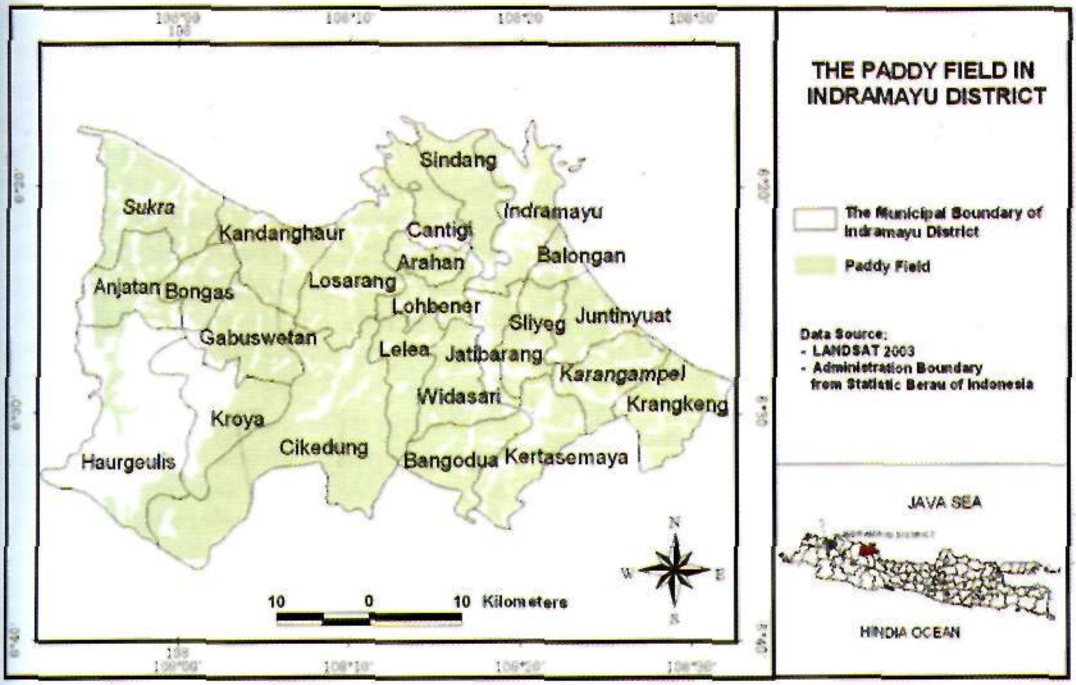


Figure 1. Paddy field area in Indramayu Distric based on Landsat-7ETM+ 2003.

4.3. Methodology

4.3.1. SPI Based on Rainfall Data

In this research, SPI was calculated to quantify the precipitation deficit using climatological rainfall data. The rainfall data have been derived from OLR data (Roswintiarti,1997) and used until now at the Indonesian National Institute of Aeronautics and Space (LAPAN) to monitoring rainfall in Indonesian region.

The classification of SPI was carried out using the method proposed by McKee *et al.* (1993) can be shown in Table 1. The negative value of SPI means drought, while the positive value means no drought.

Table 1. VHI and SPI classification schemes.

Drought Classes	VHI	SPI
Extreme drought	0<VHI<10	<-2.0
Severe drought	10 < VHI < 20	-2.0 < SPI <-1.5
Moderate drought	20 < VHI < 30	-1.5 < SPI <-1.0
Mild drought	L 30<VHI<40	-1.0 < SPI < 0.0
No drought	>40	>0.0

4J.2.VHI from MODIS Data

The preprocessing of MODIS data includes the geometric correction, sub-setting area especially Java Island, land/sea masking, and cloud removal based on Ackerman *et al.* (2003). Further processing is the LST calculation based on split window algorithm (Mao *et al.*, 2005) and

10-day NDVI calculation during the dry season (May - September) from 2003 - 2006 to get the maximum and minimum values. The processing includes the determination of VCI and TCI from NDVI and LST, respectively. Finally, the VHI values are obtained from the VCI and the TCI. The extraction of VHI values is done in the paddy field area in Indramayu District, especially in the northern part where the intensity of drought was usually high. Various drought intensities are then classified based on the VHI values (Kogan, 2002) as shown in Table l.To identify the relationship between the VHI and the drought condition in the field, the correlation analysis between the VCI, TCI and VHI with the soil moisture data were done. The soil moisture data was collected from ground survey in September 2004 and July 2005.

5. Results and Discussion

5.1. Meteorological Drought

The time series of monthly SPI (Figure 2) show that the meteorological drought in the Indramayu District generally occurred from June to September in 2003 and from August to October in 2004. In the case of 2003, the intensity of meteorological drought appeared to become mild drought (-1.0 < SPI < 0.0) from June to July 2003, then increased to become moderate drought (-1.5 < SPI <-1.0) in August 2003. The meteorological drought reached severe drought (-2.0 < SPI <-1.5) in September 2003. Meanwhile, severe drought occurred in August to September 2004, then decreased to become moderate drought in October 2004. In 2005, the meteorological drought tended to occur from July to August 2005. Generally, the meteorological drought happened in Indramayu during the dry season with various levels.

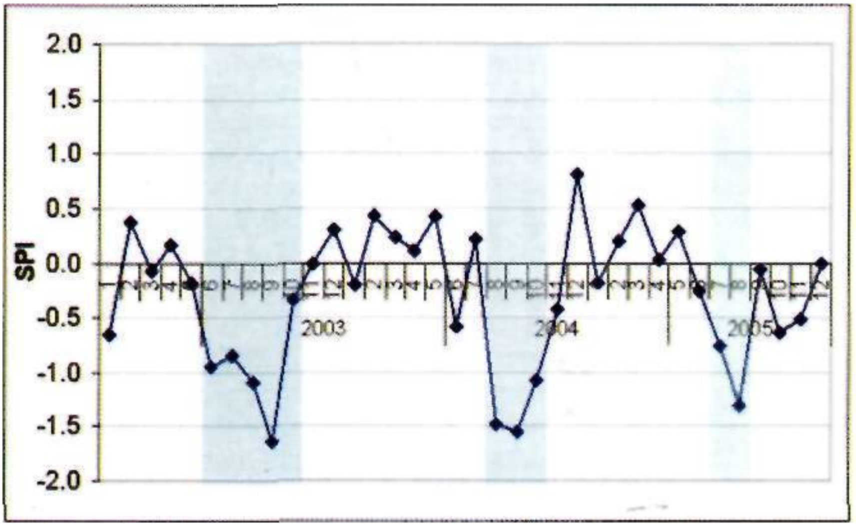


Figure 2. The SPI value during 2003-2005 based on NOAA data in Indramayu. (The blue shadding shows the potential of drought period).

5.2. Agricultural Drought

Figure 3 shows 10-day VHI, VCI and TCI during May-September (2003 - 2006) for the paddy field area in the northern part of Indramayu. In 2003, it shows that the mild drought condition (VHI < 40) started in the 3rd ten days of May. Then the drought occurred again in the beginning of July 2003 to the moderate level (VHI < 30) and increased to severe drought (VHI < 20) during the end of My until the beginning of August 2003. The peak of drought appeared in the Ist ten days of August 2003. The results correspond well with drought information reported by the Indramayu District Office of Department of Agriculture. Meanwhile, in 2004, the mild drought condition occured in June and then increased to the moderate drought in July. Although drought did not exist longer, it was shown the extreme drought appeared shortly in the end of July 2004. After that, the drought tended to decrease with increasing VCI and TCI which represented the paddy in the favorable condition. The intensity of drought in 2004 was lower than that in 2003. This is due to the El Nino phenomena in 2003. Unlike 2003 and 2004, the intensity of drought in 2005 and 2006 were lower. The drought happens every year in Indramayu especially in dry season from June - August with the various intensities.

Spatial distribution of VHI images during June-August 2003 in Indramayu District can be seen in Figure 4. It shows that drought began to appear almost in all over the Indramayu District in the first ten days of June 2003. The drought level in the northern part of Indramayu was higher than that in the southern part. The vegetation became normal until the first ten days of July, except the small part in the north which still experienced drought. Then, the drought increased especially in the northern and the southern parts of Indramayu and reached its peak in the first tend days of August 2003. Some regions in the northern and the southern parts of Indramayu suffered with the extreme drought (VHI<10).

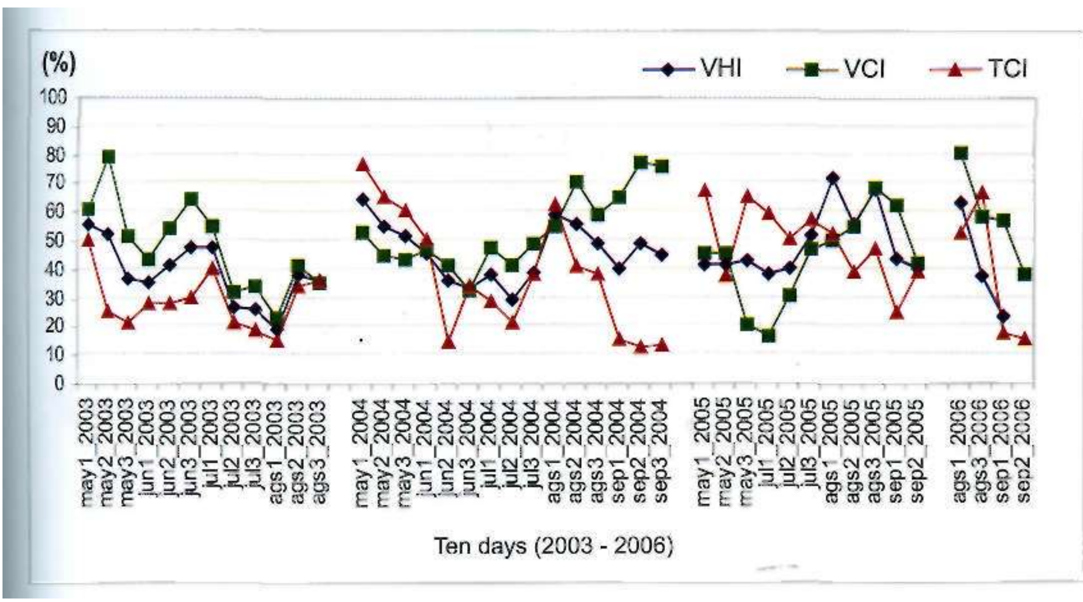


Figure. 3. The 10 days time scries of VHI, VCI and TCI in the period of May-September 2003-2006 extracted in paddy area in the north part of Indramayu District.

From Figure 4 we know that the potential areas of drought were in the northern and the southern parts of Indramayu. The municipal in the northern part of Indramayu which are very sensitive to drought condition are Sukra, Kandanghaur, Cantigi, Losarang, Indramayu, Balongan, Juntinyuat, Karangampel, Krangkeng, while in the southern part are Kertasemaya, Bangodua, Cikedung, Kroya, and Haurgeulis. Compared with 2003, the drought conditions in all Indramayu District in 2004 were lower. The distribution area of drought was still concentrated in the northern part of Indramayu and small part in the south with the lower intensity. In general, mild to severe drought existed in the northern and the southern parts of Indramayu in the second ten days of June and lasted until August 2004. The extreme drought (VHI < 10) appeared in the second ten days of July 2004. Meanwhile, in August 2004 mild drought occurred sparsely in Indramayu District. The temporal and spatial distribution of VHI in 2004 can be seen in Figure 5.

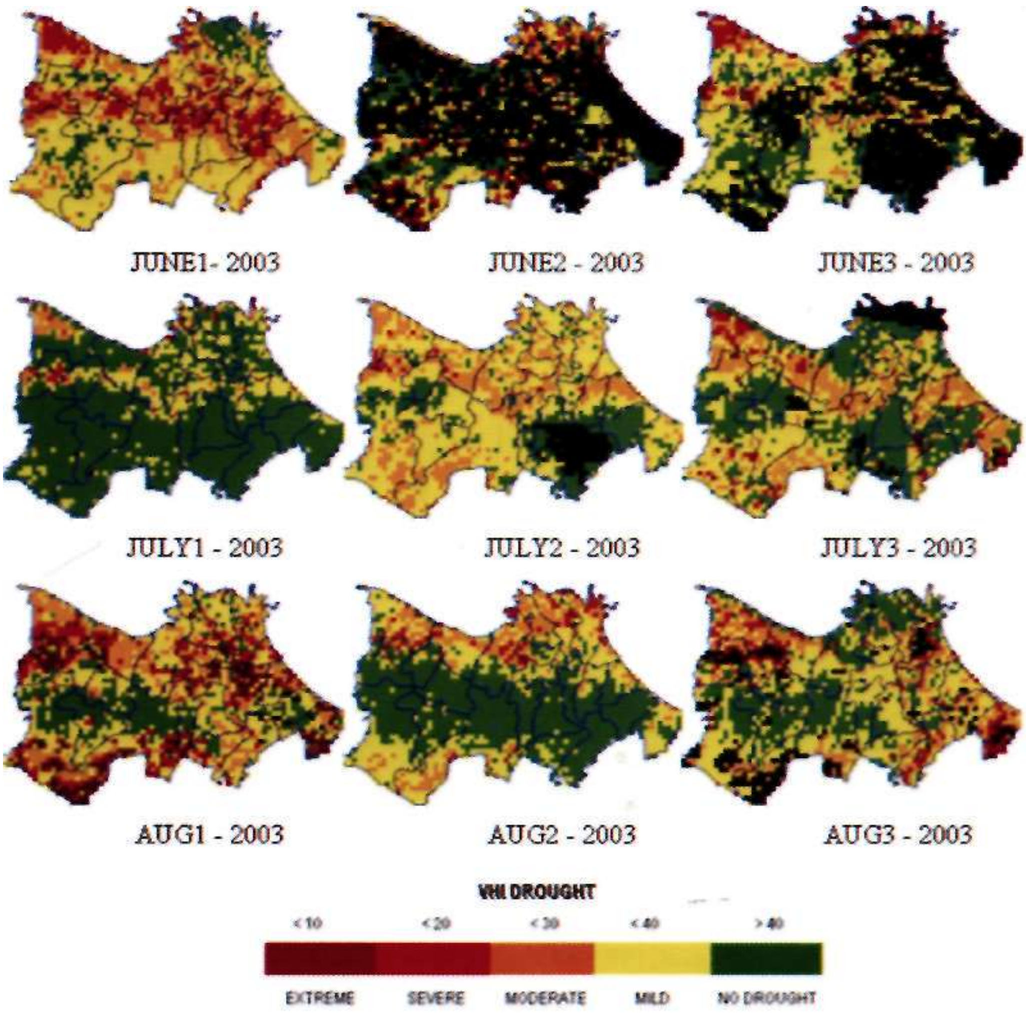


Figure 4. Spatial distribution of drought classification based on 10 days average of VHI using MODIS data during June-August 2003 in Indramayu District. (Note: the black area means no data).

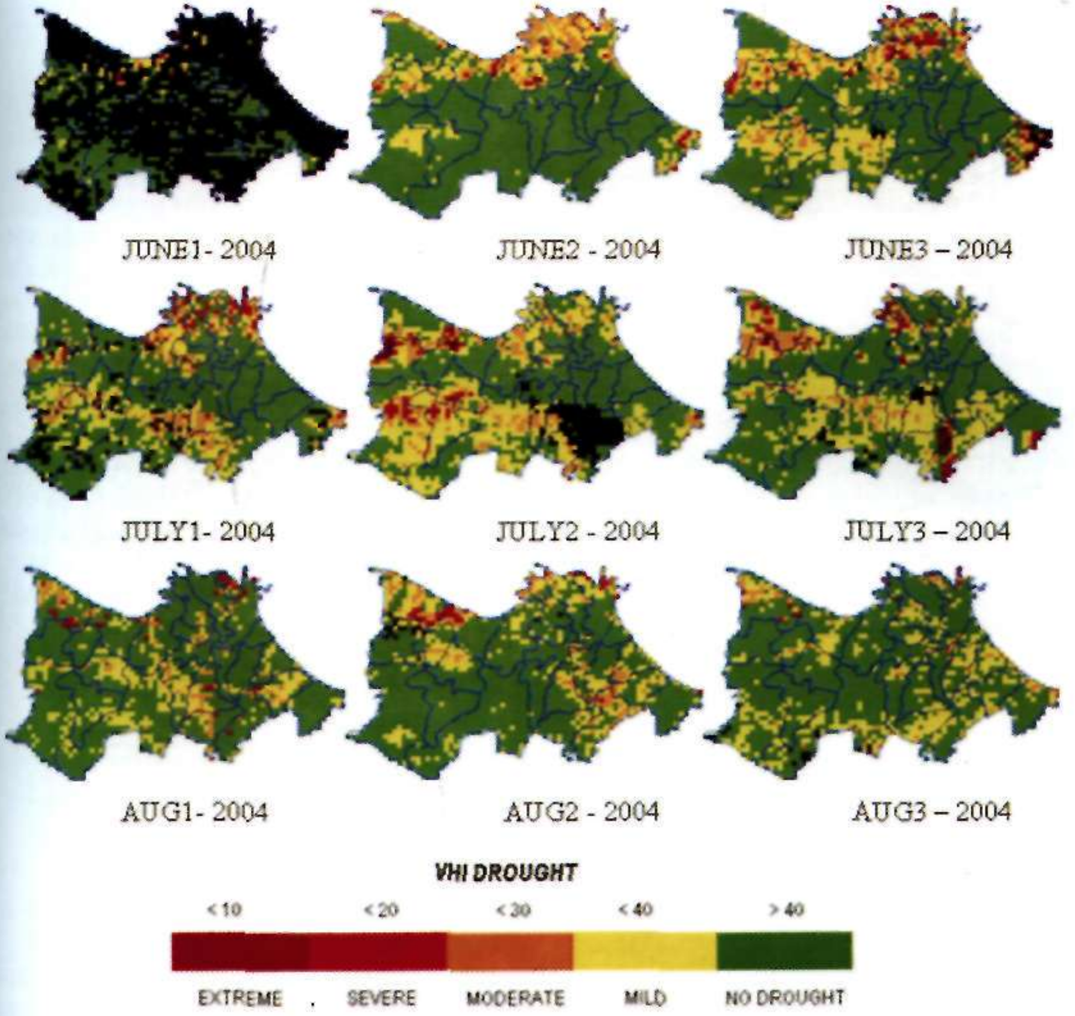
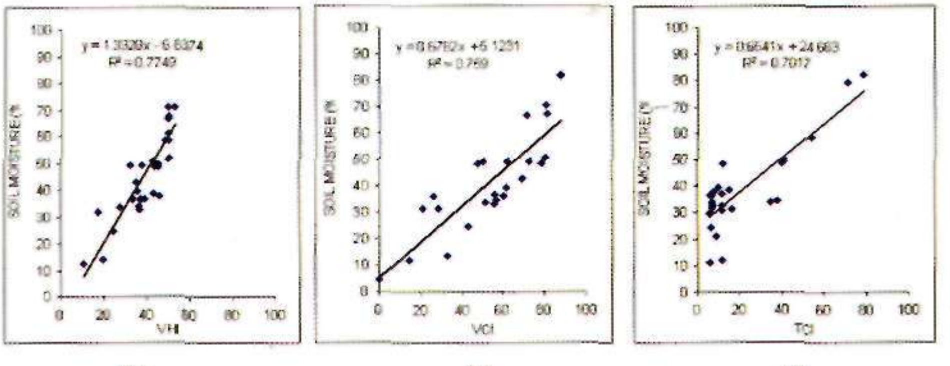


Figure 5. Spatial distribution of drought classification based on 10-days average of VHI using *MODIS* data during *June–August 2004* in *Indramayu District. (Note: the black area*



(a) (b) (c)

Figure 6. The relationship between soil moisture with VHI (a), VCI (b), and TCI (c) in Java Island.

To investigate the relationship between the agricultural indices and the water stress, the correlation analysis was done using soil moisture data from the field survey in 2004 and 2005. The result shows thai the VHI. VCI and TCI have a linear positive relationship with soil moisture (Figure 6). Increasing of vegetation drought indices refers to (he favorable condition of vegetation and soil moisture. Significant correlations between vegetation drought indices and the soil moisture data are shown from the coefficients of correlation, i.e. 0.88, 0.87, 0.84 for VIII, VCI and TCI, respectively. Therefore, those drought indices could also be used for indicating soil moisture condition in Java Island.

S3. The Relationship Between Meteorological and Agricultural Drought

Based on the above results, there is a significant relationship between VHI and SPI , especially during the dry season (June - August) in 2003 and 2004. In general, when the meteorological drought appeared then the agricultural drought occurred. However, in 2005 the SPI indicated negative value (deficient rainfall) but the VHI showed the favorable condition. In this case, the SPI did not correspond directly to agricultural drought. The soil moisture during (he dry season in 2005 seemed to be enough to support the vegetation growth. It can be represented by the high of VCI and TCI during July to August 2005. The high of VCI means the vegetation is in favorable moisture condition and represents the unstressed vegetation. Meanwhile, high TCI value corresponds to the unstressed vegetation due to low dryness by low temperature. We can conclude that the meteorological drought (SPI) as the potensial of drought while the agricultural drought (VHI) can show more actual drought due to the real time monitoring.

5.4. The Application of VHI Model for Drought Monitoring over Java Island

Figure 7 shows the application of VHI model for drought monitoring over Java Island using MODIS data on August 2, 2003. The bright red area shows the severe drought. According to the information from the Departmen of Agriculture, the drought condition associated well with those shown in Figure 7. The drought areas in August 2003 were identified in Indramayu, Subang, Purwakarta, Karawang, Semarang. Lamongan, and Grcsik Districts.

In order to increase the accuracy of the VHI model, the verification of the VHI's intervals which represent the agricultural drought levels in the field should be done. For furthere analysis, the VHI values would be used to predict the acreage of drought.

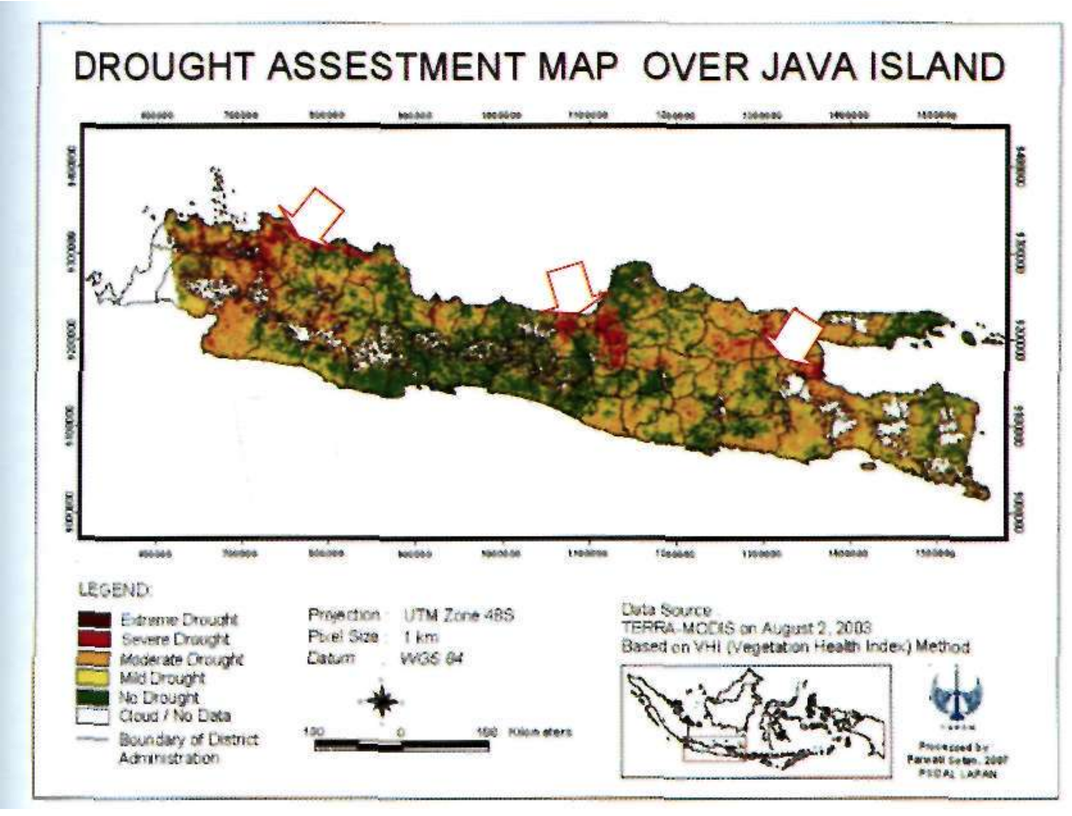


Figure 7. The drought assessment map over Java Island based on VHI from the MODIS data on August 2,2003.

6. Conclusion

This paper describes the meteorological and agricultural drought monitoring using remotely sensed indices' derived from MODIS data. It could be concluded that:

- The VHI could indicate the occurrence of agricultural drought in Indramayu District, especially in the northern part of Indramayu during the dry season in 2003 and 2004.
- The VHI could also be used for monitoring agricultural drought for larger area, such as Java Island.
- It is found that there is a strong correlation between VHI and soil moisture measured in the field.
- The VHI is a good indicator of the agricultural drought condition and could represent actual drought information, while the SPI is a good indicator of potential drought condition.

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