MONITORING OF DROUGHT-VULNERABLE AREA IN JAVA ISLAND, INDONESIA USING SATELLITE REMOTE-SENSING DATA

Orbita Roswintiarti, Parwati Sofan, and Nanin Anggraini
Remote Sensing Applications and Technology Development Center, LAPAN
e-mail: orbita@lapan.go.id

ABSTRACT

The impact of climatic variability and climate change is of great importance in Indonesia. Monitoring this impact, furthermore, is essential to the preparedness of the regions in dealing with drought-vulnerable conditions. In this study, satellite remote sensing data were used for monitoring drought in Java island, Indonesia. Monthly rainfall data from Tropical Rainfall Measuring Mission (TRMM) data were used to derive the Standardized Precipitation Index (SPI). The Moderate Resolution Imaging Spectroradiometer (MODIS) onboard the Terra and Aqua satellites was used for calculating the Enhanced Vegetative Index (EVI) and Land Surface Temperature (LST). EVI and LST were then converted to the Vegetation Condition Index (VCI) and the Temperature Condition Index (TCI), which are useful indices for the estimation of vegetation moisture and thermal conditions, respectively. Vegetation Health Index (VHI) was calculated using the VCI and TCI to represent the overall vegetation health.
The analysis was carried out during the El Niño/Southern Oscillation (ENSO) of June to August 2009. From the SPI analysis, it is found that since June 2009 the conditons of mild drought ($-1.0 \le SPI < 0$) have developed in almost all parts of Java island due to rainfall deficiency. The VCI maps show that the vegetative stress ($VCI < 36$) as a result of the vegetation moisture condition has gradually developed in the East Java province in June 2009. Meanwhile, from the TCI maps it is found that the vegetative stress ($TCI < 36$) due to the thermal condition of vegetation was built up in the West Java province in June 2009. Hence, the overall vegetative health in Java island obtained from the VHI maps shows that the moderate vegetative drought ($VHI < 36$) started to develop in July 2009.

Keywords: *Java island, TRMM, EVI, SPI, VCI, TCI, VHI*

ABSTRAK

Dampak variabilitas iklim dan perubahan iklim sangat penting bagi Indonesia. Pemantauan terhadap dampak ini, sangatlah penting bagi daerah yang rentan terhadap kondisi kekeringan dalam kesiapan menghadapinya. Dalam studi ini, digunakan data satelit penginderaan jauh untuk memantau kekeringan di pulau Jawa Indonesia. Data curah hujan bulanan dari curah hujan Tropis Mengukur Misi (TRMM) digunakan untuk menurunkan hujan Indeks Standar (SPI). Resolusi Moderat Imaging Spectroradiometer (MODIS) *onboard* satelit Terra dan Aqua digunakan untuk menghitung Indeks vegetatif Disempurnakan (EVI) dan suhu permukaan tanah (LST). EVI dan LST kemudian dikonversi ke Indeks Kondisi Vegetasi (VCI) dan Indeks Kondisi Suhu (TCI), yang digunakan untuk estimasi kelembaban vegetasi dan kondisi termal, masing-masing. Vegetasi Indeks Kesehatan (VIII) dihitung dengan menggunakan VCI dan TCI untuk mewakili kesehatan vegetasi secara keseluruhan. Analisis dilakukan selama *El Nino/SouthernOscillation* (ENSO) Juni hingga Agustus 2009. Dari analisis SPI, ditemukan bahwa sejak Juni 2009 kondisi kekeringan ringan ($1,0 \le SPI<0$) telah berkembang di hampir seluruh bagian pulau Jawa karena kekurangan curah hujan. Peta VCI menunjukkan bahwa stres vegetatif (VCI <36) sebagai akibat kondisi kelembaban vegetasi secara bertahap bertambah di Provinsi Jawa Timur pada bulan Juni 2009. Sementara itu, dari peta TCI ditemukan bahwa stres vegetatif (TCI <36) karena kondisitermal vegetasi telah terjadi di provinsi Jawa Barat pada bulan Juni 2009. Oleh karena itu, kesehatan vegetatif secara keseluruhan di pulau Jawa yang diperoleh dari peta VIII menunjukkan bahwa kekeringan vegetatif sedang (VIII <36) mulai berkembang pada bulan Juli 2009.

Kata kunci: *Pulau Jawa, TRMM, EVI, SPI, VCI, TCI, VHI*

1 INTRODUCTION

Drought is a serious natural hazard characterized by lower than normal precipitation that when extended over a longer period of time is insufficient to meet the demands of human activities and the environment. Drought must be considered a relative rather than an absolute condition, because it occurs in all climate regimes.

Drought is a regional phenomenon and its characteristics differ from one climate region to another. It becomes a disaster when its impacts influence local people, economies, environment, and the ability to cope with and recover from it. Drought differs from other natural hazards in various ways.

Commonly, drought is classified by type as meteorological, agricultural, and hydrological droughts (Wilhite, 2006). Meteorological drought is usually defined by a precipitation deficiency threshold over a predetermined period of time. Agricultural drought is defined more commonly by availability of soil water to support crop and forage growth than by the departure of normal precipitation. Hydrological drought is even further removed from the precipitation deficiency since it is normally defined by the departure of surface and subsurface water supplies from some average condition at various points in time.

Timely information about the onset of drought, its extent, intensity, duration, and impacts could limit drought-related losses of life, minimize human suffering, and reduce damage to the economy and environment (Wilhite, 1993). The sparsity of weather stations and the unavailability of their data make drought monitoring a daunting task. Therefore, the use of satellite remote sensing data would avoid some of these problems. Drought monitoring and early warning are major components of drought risk management which its is to increase society's coping capacity, leading to greater resilience and a reduced need for government or donor interventions in the form of disaster assistance. Many information related with drought monitoring is available online for some countries. Figure 1-1 is an example of remote sensing-based drought monitoring product in Asia for 22-28 July 2009 (week 29) obtained from National Environmental Satellite, Data and Information Service (NESDIS) - National Oceanic and Atmospheric Administration (NOAA) at http://www.star.nesdis.noaa.gov.

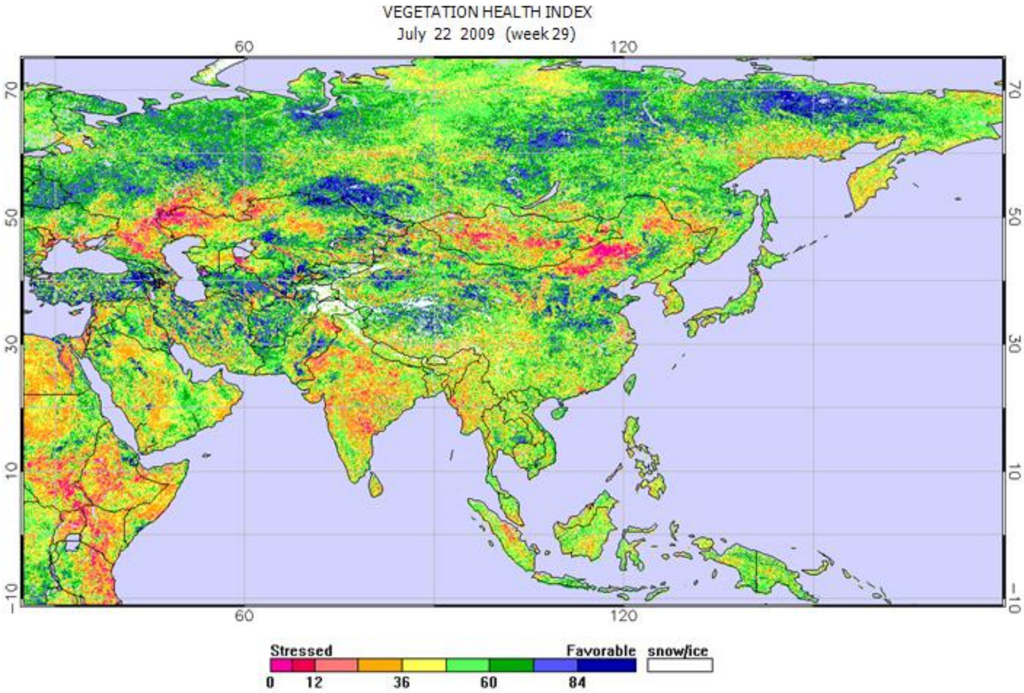


Figure 1-1:Remote sensing-based Vegetation Health Index over Asia for 22-28 July 2009 (Source: http://www.star.nesdis.noaa.gov)

In Indonesia, drought and severe vegetation stress were closely related with ENSO events. Beside affecting drought, ENSO had also significant consequences for agricultural output, rural incomes, and staple food prices (Naylor et al. 2001, Falcon et al. 2004). As it is known, ENSO is a disruption of the ocean-atmosphere system in the tropical Pacific having important consequences for weather and climate around the globe. The drought-related ENSO were firstly felt in the eastern and central parts of Indonesia often sufferred droughts in June-August. During this period, the southwest monsoon was often weaker, although by no means always. In September-November, the impacts of ENSO were strongest. Almost all regions in Indonesia were drier than normal.

During the past two decades, there were four strong ENSO events (1982/83, 1986/88, 1991/92, and 1997/98), four moderate ENSO events (1994/95, 2002/03, 2006/07, and 2009), and two weak ENSO events (1993 and 2004/05). Figure 1-2 shows the Nino 3.4 index and its associated ENSO events from January 1982 to October 2009. By definition, an ENSO occurs if the five-running mean of sea surface temperature anomaly in the Nino 3.4 region (5°N-5°S; 120°-170°W) exceeding +0.4°C for 6 months or more (Trenberth 1997).

Over the longer run, the rising concentrations of greenhouse gases will likely create additional climate impacts, such as global warming. The combined forces of ENSO and global warming could have dramatic, and currently unforeseen, effects on agricultural production in Indonesia and other tropical countries.

In this paper, detailed analysis of drought dynamics in Java island, Indonesia has been carried out to identify the spatio-temporal drought patterns in terms of both meteorological and vegetative aspects. The analysis has been focused on drought conditions in June to August 2009 of moderate ENSO event. The Standardized Precipitation Index has been used to monitor the meteorological drought. Vegetation Condition Index, Temperature Condition Index, and Vegetation Health Index have been employed to assess the agricultural drought.

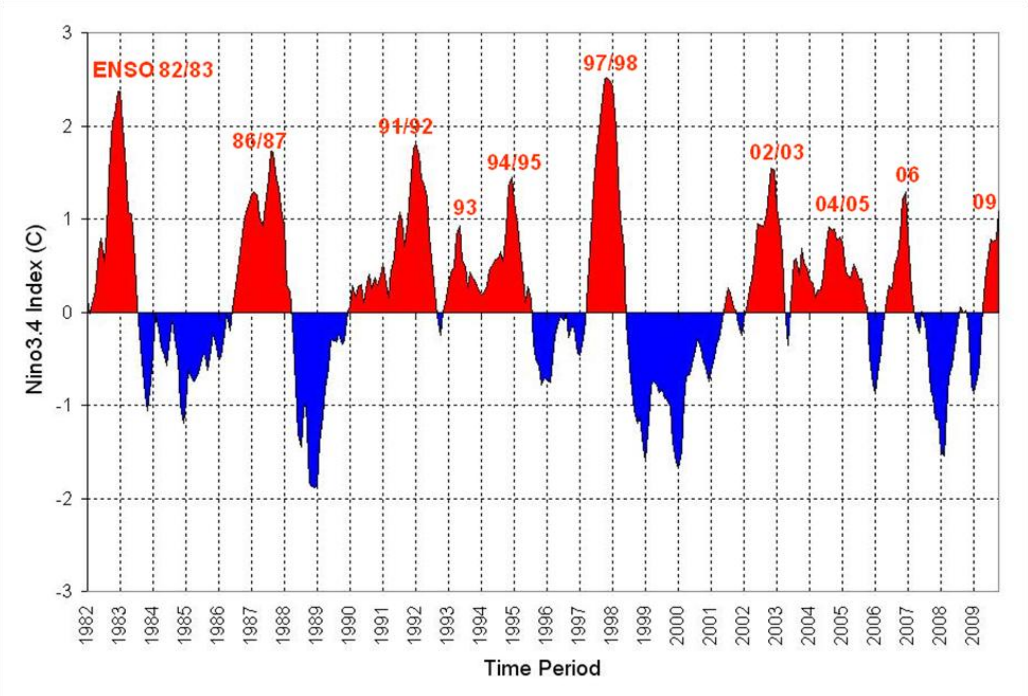


Figure 1-2: Time series of Nino 3.4 index and its associated ENSO events

2 METHODOLOGY

2.1 Standardized Precipitation Index

Rainfall is a fairly good source of information used for drought assessment. There are several indices that measure how much rainfall for a given period of time has deviated from its established normal. Although none of the major indices is inherently superior to the rest in all circumstances, some indices are better suited than others for certain uses. One of the common meteorological drought indices is Standardized Precipitation Index (SPI).

The SPI is computed by dividing the difference between the normalized monthly rainfall and its long-term mean by the standard deviation. Thus,

$$SPI = \frac{X_{ij} - X_{im}}{\sigma} \qquad (2\text{-}1)$$

where X_{ij} is rainfall at the i^{th} location and j^{th} time, X_{im} is the long-term mean rainfall at the i^{th} location, and σ is its standard deviation. Five classes of SPI described in Mc Kee et al. (1993) is shown in Table 2-1.

Table 2-1: SPI CLASSIFICATION

SPI	Classes
SPI ≥ 0.0	No drought
-1.0 ≤ SPI < 0	Mild drought
-1.5 ≤ SPI < -1.0	Moderate drought
-2.0 ≤ SPI < -1.5	Severe drought
SPI < -2.0	Extreme drought

2.2 Vegetation Condition Index, Temperature Condition Index, and Vegetation Health Index

Vegetative or agricultural drought reflects vegetation-stress caused due to adverse climatic and hydrologic factors. Parameter of so-called Enhanced Vegetation Index (EVI) reflects the vegetation condition through the ratio of responses in near-infrared and visible wavelengths. Healthy vegetation given by the higher positive EVI absorbs most of the visible light that hits it and reflects a large portion of the near infrared light. Meanwhile, unhealthy or sparse vegetation given by the lower positive EVI reflects more visible light and less near infrared light. In EVI, strong ecological component subdues the weather component. EVI is defined as:

$$EVI = \frac{r_{NIR} - r_{Red}}{r_{NIR} + C_1 r_{Red} - C_2 r_{Blue} + L} xG \quad (2\text{-}2)$$

where r_{NIR}, r_{Red}, and r_{Blue} are the reflectance in near-infrared, red, and, blue bands, respectively. The coefficients C_1, C_2, and L are empirically determined as 6.0, 7.5, and 1.0, respectively. G is the gain factor and equals to 2.5.

Vegetation Condition Index (VCI) separates the short-term weather-related EVI fluctuations from the long-term ecosystem changes (Kogan 1990, 1995). Therefore, VCI could be used as one of indices to identify the vegetative stress due to the moisture conditions of vegetation. VCI is given as:

$$VCI = 100x \frac{EVI - EVI_{min}}{EVI_{max} - EVI_{min}} \quad (2\text{-}3)$$

where EVI, EVI_{max}, and EVI_{min} are the maximum of eight-day EVI, its multi-year maximum, and minimum, respectively. VCI varies in the range 0 and 100 to reflect relative changes in the vegetation condition from extremely bad to optimal (Kogan 1995, Kogan et al., 2003).

Since temperature, wind, and relative humidity are also important factors to include in characterizing drought, one of the common indices employed as temperature-related vegetative stress is Temperature Condition Index (TCI). TCI represents the relative change in thermal condition in terms of land surface temperature whose values are obtained from the thermal bands. TCI is used to determine temperature-related vegetation stress and also stress caused by excessive wetness. TCI is given as:

$$TCI = 100x \frac{LST_{max} - LST}{LST_{max} - LST_{min}} \quad (2\text{-}4)$$

where LST, LST_{max}, and LST_{min} are the average of eight-day land surface temperature, its multi-year maximum, and minimum, respectively. It is shown in Equation 4 that TCI is the opposite response of vegetation to temperature.

While VCI and TCI characterize the varying moisture and thermal conditions of vegetation, Vegetation Health Index (VHI) represents overall vegetation health used for drought mapping. VHI is computed and expressed as:

$$VHI = 0.5(VCI + TCI) \quad (2\text{-}5)$$

Kogan (2002) divided VHI into five classes, i. e. no drought, mild drought, moderate drought, severe drought, and extreme drought (Table 2-2).

Table 2-2: VHI CLASSIFICATION

VHI	Classes
VHI > 40	No drought
30 < VHI ≤ 40	Mild drought
20 < VHI ≤ 30	Moderate drought
10 < VHI ≤ 20	Severe drought
VHI ≤ 10	Extreme drought

3 DATA AND STUDY AREA

In this study, the monthly rainfall data of the TRMM were used to derive the SPI. The TRMM3B43.6 dataset is available at a 0.25° x 0.25° resolution from Goddard Space Flight Center (GSFC) – USA National Aeronautics and Space Administration (NASA) at http:// trmm.gsfc.nasa.gov and Earth Observation Research Center (EORC)-Japan Aerospace Exploration Agency (JAXA) at http:// www.eorc.jaxa.jp/TRMM. Various research and applications of TRMM data have been conducted previously (Meneghini et al., 2004; Mori et al., 2004; Wolff et al., 2005, Ichikawa and Yasunari 2006, Shige et al., 2007). For the SPI calculation, the monthly long-term mean rainfall is calculated from January 1998 to December 2008 (11 years).

The eight-day surface reflectances and LST data used to calculate respective EVI and LST have been deduced from the Terra/Aqua MODIS data. The EVI at a spatial resolution of 250 meter is calculated from the surface reflectances derived from the MOD09A1 and MOD09Q1 algorithms. Meanwhile, the LST is derived from the MOD11A2 algorithm and available at a spatial resolution of 1000 meter. For this study, the EVI and LST data of two years from January 2007 to December 2008 have been used to calculate their maximum and minimum values. EVI and LST were then converted to the VCI, TCI, and VHI.

The focused area of this study is Java island in Indonesia. Java island is located between 5°52'S and 8°52'S from 105°7'E to 114°37'E. In Java island, the rainy season occurs maily in December-February associated with the northeast Asia-Australia (AA) monsoon, while the dry season commonly happens in June-August during the southwest AA monsoon. The agricultural activities in Java island are influenced and controlled directly by rainfall and availability of water resources in the irrigation systems. Rice is the main crop in Java island. In normal conditions (neutral ENSO years), depending on the availability of irrigated water, the main wet season rice crop in Java island is planted between late October and early December and harvested between January and March. A smaller dry season planting takes place in April-May and harvested in July-August (Falcon et al., 2004).

4 RESULTS AND DISCUSSION

4.1 Meteorological Drought

To comprehend the use of TRMM data in analyzing the characteristics of rainfall over Indonesia, Figure 4-1a-b show the spatial distribution of the overall long-term mean (132 months) and its standard deviation of rainfall. It is shown that the intensity in the amount of 200-250 mm/month occurs in southern part of West Java, southern part of Central Java, and central part of East Java. Meanwhile, the rest of the areas has rainfall intensity of 150-200 mm/month. Java island has much lower rainfall intensity compared with Sumatera, Kalimantan, Sulawesi, and Papua. The standard deviation of rainfall over eastern part of West Java, Central Java, and East Java ranges between 140-180 mm/month, whereas the lower standard deviation of rainfall (<140 mm/month) takes place in the western part of West Java.

Figures 4-2a-c present the SPI distribution in Java island from June to August 2009, respectively. It is shown that entire Java island suffered with drought during this period. In June 2009, mild drought ($-1.0 < SPI \leq 0$) dominated entire island, while moderate drought ($-1.5 \leq SPI < -1.0$) occurred mainly in the eastern part of East Java. The intensity of the moderate drought in West Java became extended in July 2009. In August 2009, most of Java island suffered with moderate drought while some part of West Java experienced severe drought. This worsen condition was caused by a very low and no rainfall felt in August 2009. It should be noted that the meteorological drought only considers the reduction in rainfall amounts and do not take into account for example the effects of the lack of water on water reservoirs.

a)

b)

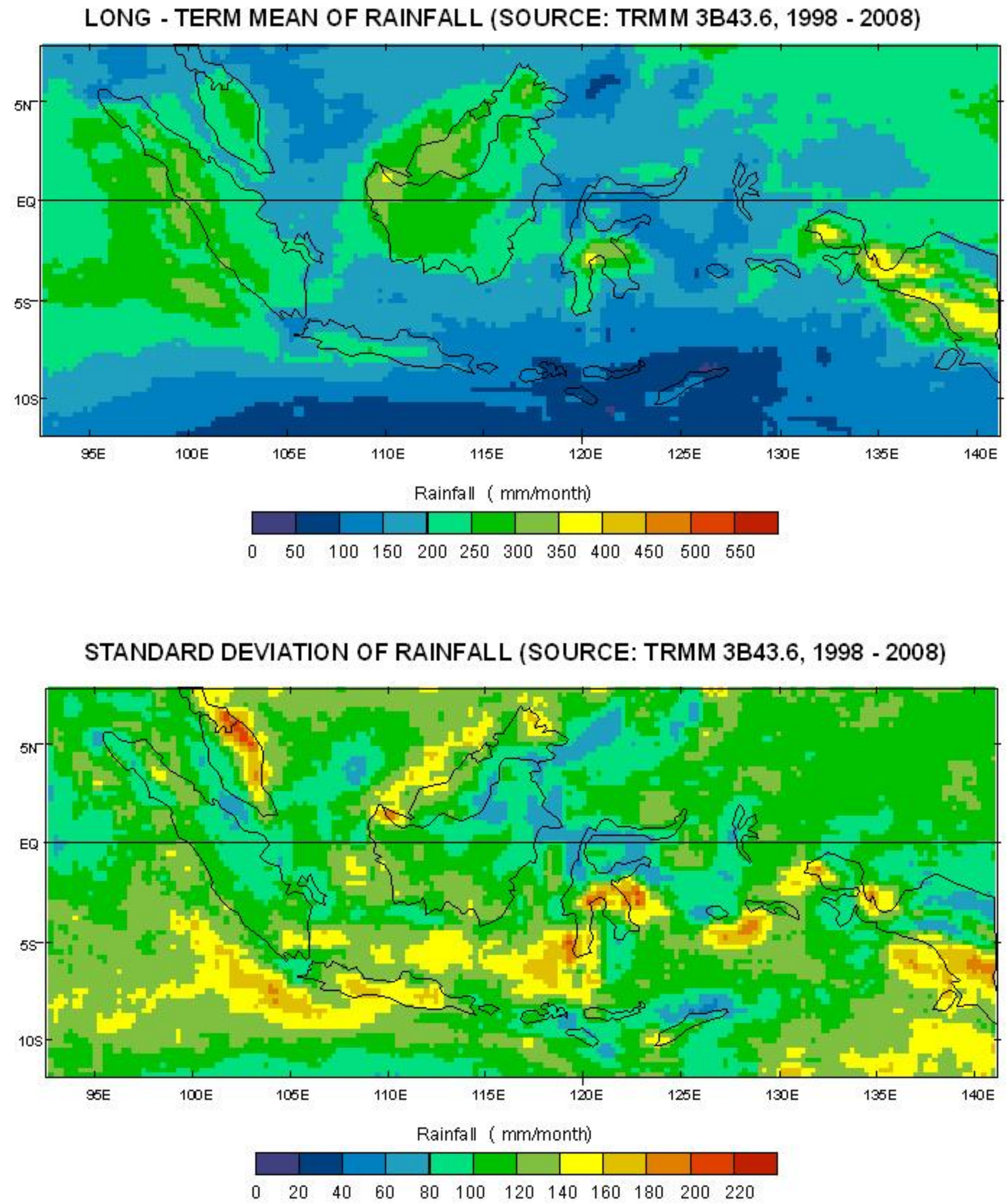


Figure 4-1: The overall long-term a) mean and b) standard deviation of the rainfall over Indonesia

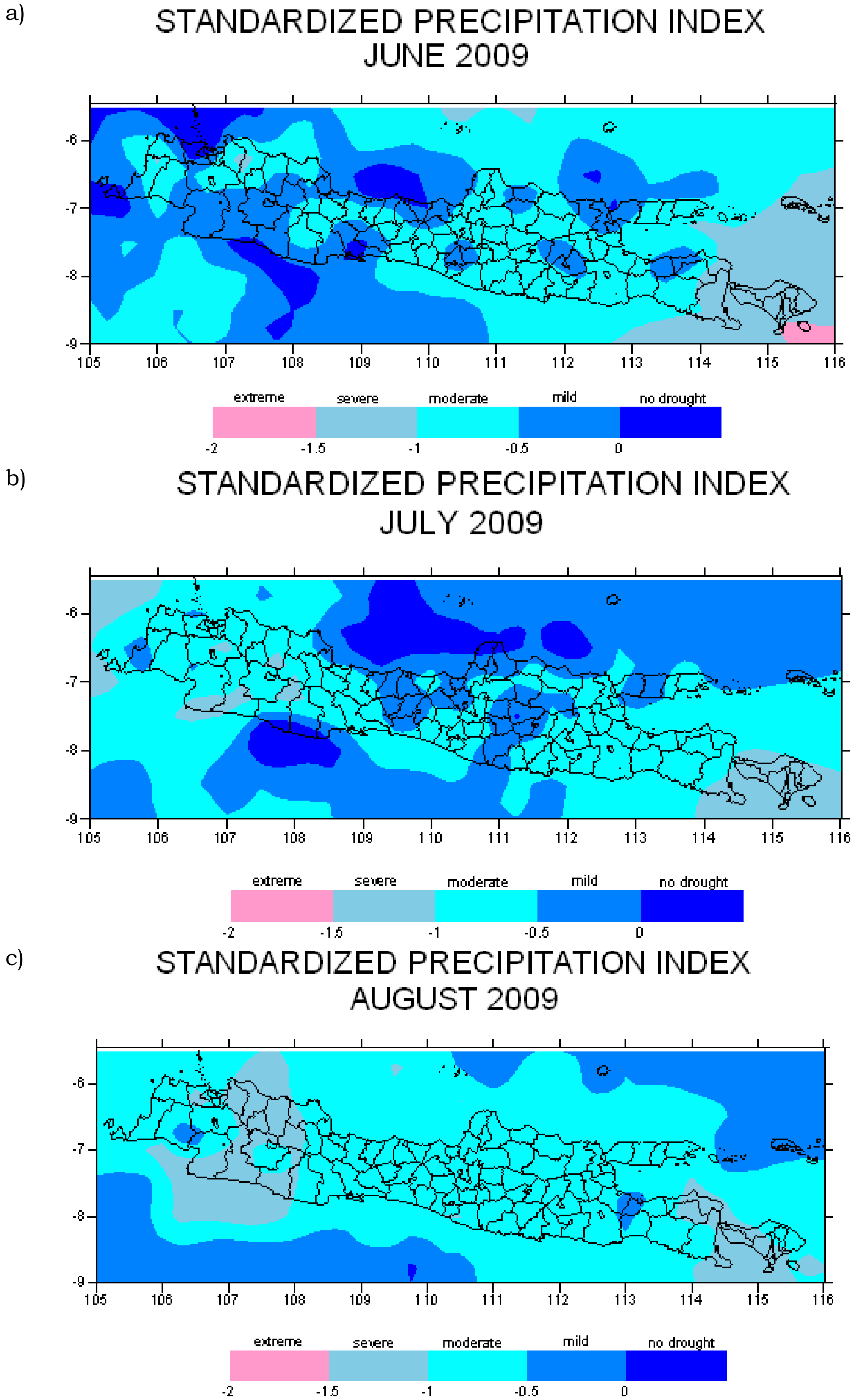


Figure 4-2: SPI distribution in Java island for a) June 2009, b) July 2009, and c) August 2009

4.3 Agricultural Drought

Monthly VCI, TCI, and VHI maps are calculated from the average of eight-day data. It should be noticed that the VCI, TCI, and VHI values in this paper are evaluated based on the maximum and minimum values of EVI and LST of January 2007 to December 2008.

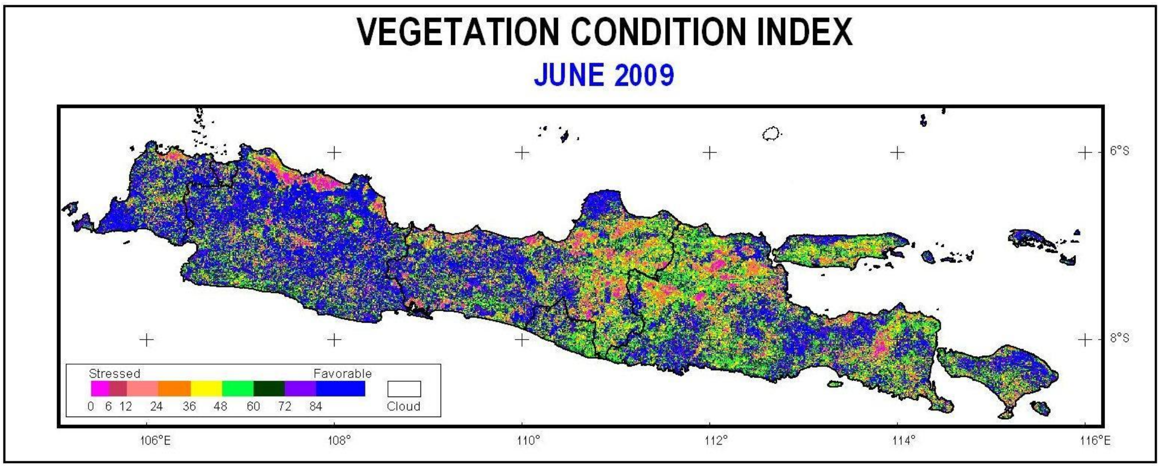
From the VCI distribution, it is shown that in June 2009 the normal/ favorable vegetation condition (VCI > 84) took place mostly in West Java and Central Java, while vegetative stress (VCI < 36) as a result of the vegetation moisture condition happened in northern West Java and some parts in East Java (Figure 42a). In July 2009, the favorable vegetation in West Java and Central Java gradually decreased resulted in wider areas of unfavorable vegetation (VCI < 60) in Java island (Figure 4-2b). In August 2009, condition of vegetative stress (VCI < 36) was dominated Java island (Figure 4-2c).

The TCI distribution in June 2009 shows that the vegetative stress due to the temperature condition (TCI < 36) has occurred in most of West Java and Central Java and southeastern part of East Java, while the favorable vegetation was still found in the northeastern part of West Java and northern part of East Java (Figure 4-3a). In July 2009, the areas of the favorable vegetation were getting lesser (Figure 4-3 b). In August 2009 (Figure 4-3c), Java island was dominated by stress vegetative condition (TCI < 36) where some areas in central part of Java island had TCI < 12. Since the temperatures remained high, as a result low TCI values are found in August 2009.

To express the additive approximation of vegetative stress for analyzing the vegetative drought, the VHI distribution in Java island is presented in Figure 4-4a-c. In June 2009, Java island was still dominated by fair and favorable vegetation health condition (VHI > 48). The northern part of West Java and some areas in East Java experienced stress condition (VHI < 36). In July 2009, as VCI and TCI were getting lower, the resulted VHI was also getting lower. In August 2009, Java island was influenced by moderate drought particularly in northern and southern parts, meanwhile severe drought more in the middle part.

Agricultural drought is typically seen after meteorological drought. It is important to mention that the effects of droughts are different in irrigated and non-irrigated agriculture. Eventhough in this paper no explanation about the irrigated and non-irrigated regions, commonly in regions which rely on irrigation, the impacts of agricultural droughts are usually lower than in regions where crops are not irrigated. This is because in the irrigated agriculture, crops rely on stocks of water in the reservoirs. On the other hand, in non-irrigated agriculture crops depend directly on the rainfall whereas if there is no rainfall the crops do not get the water they need to survive.

a)



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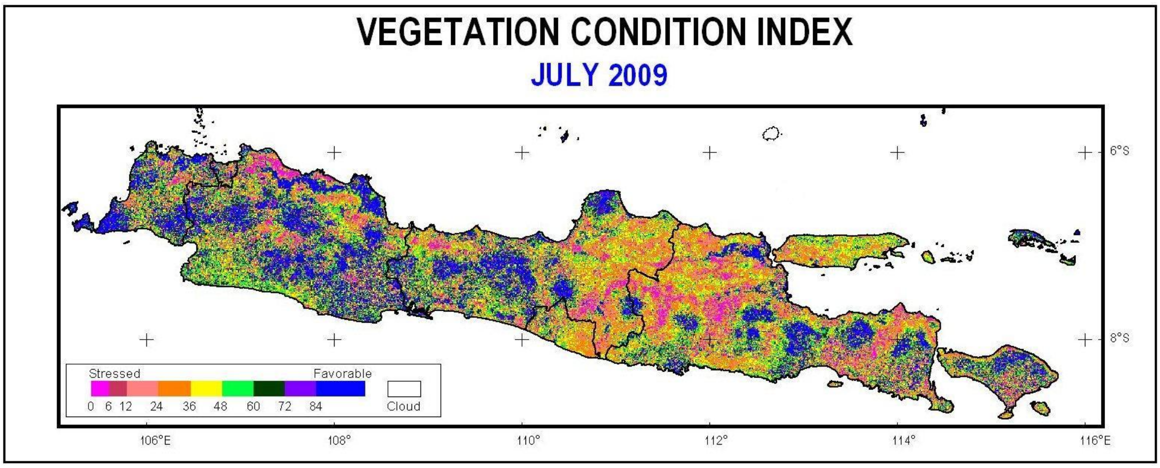

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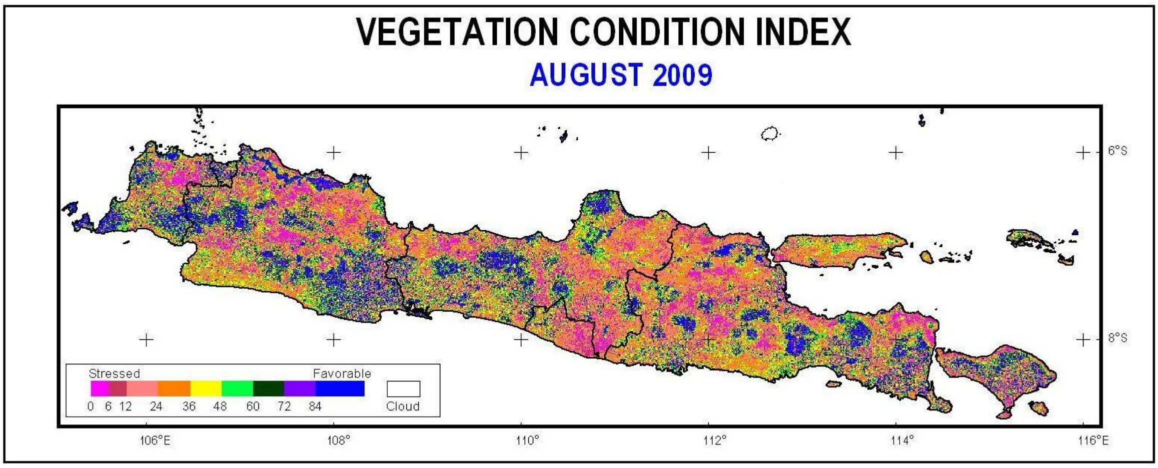

Figure 4-3: VCI distribution in Java island for a) June 2009, b) July 2009, and c) August 2009

a)
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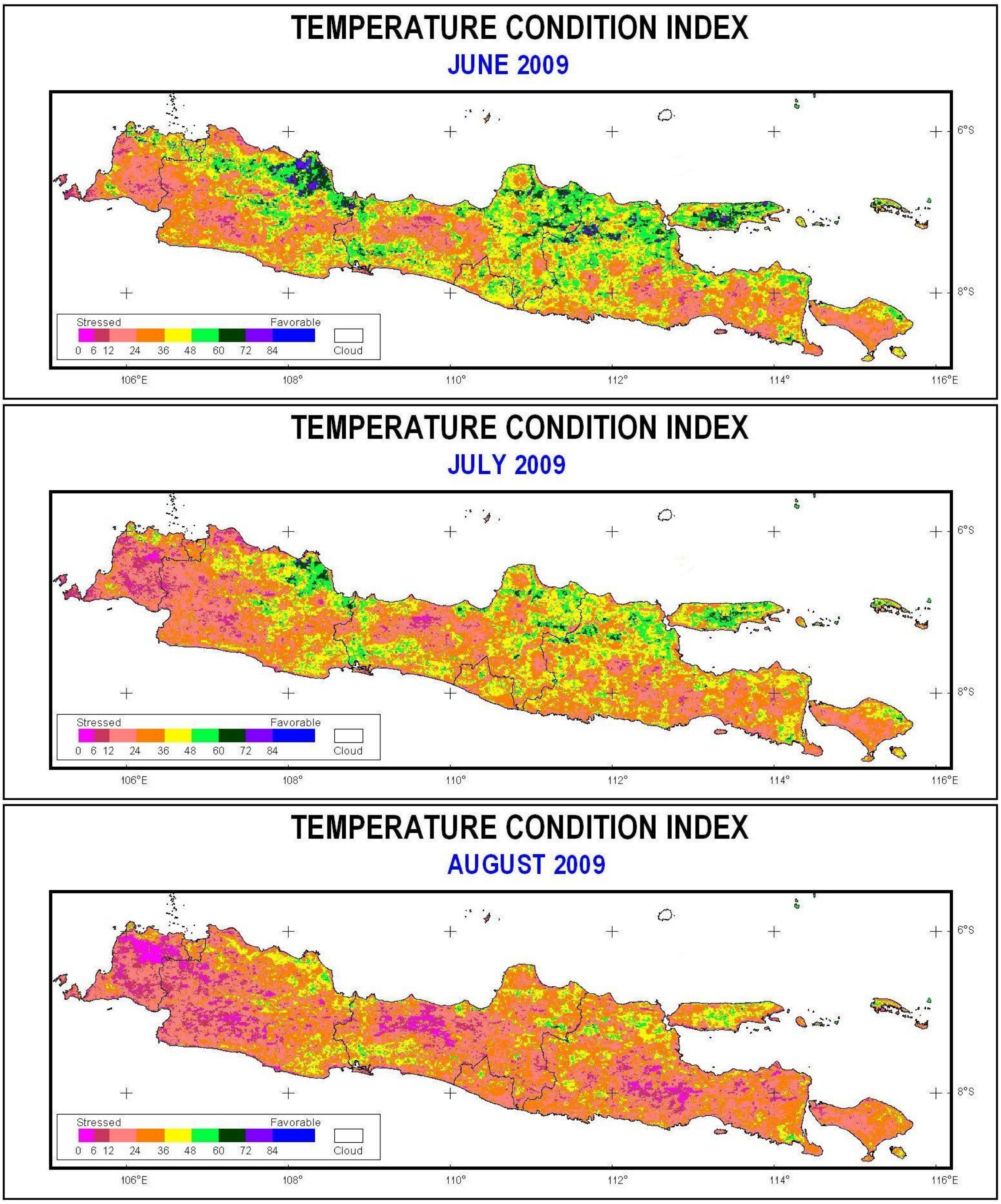

Figure 4-4: TCI distribution in Java island for a) June 2009, b) July 2009, and c) August 2009

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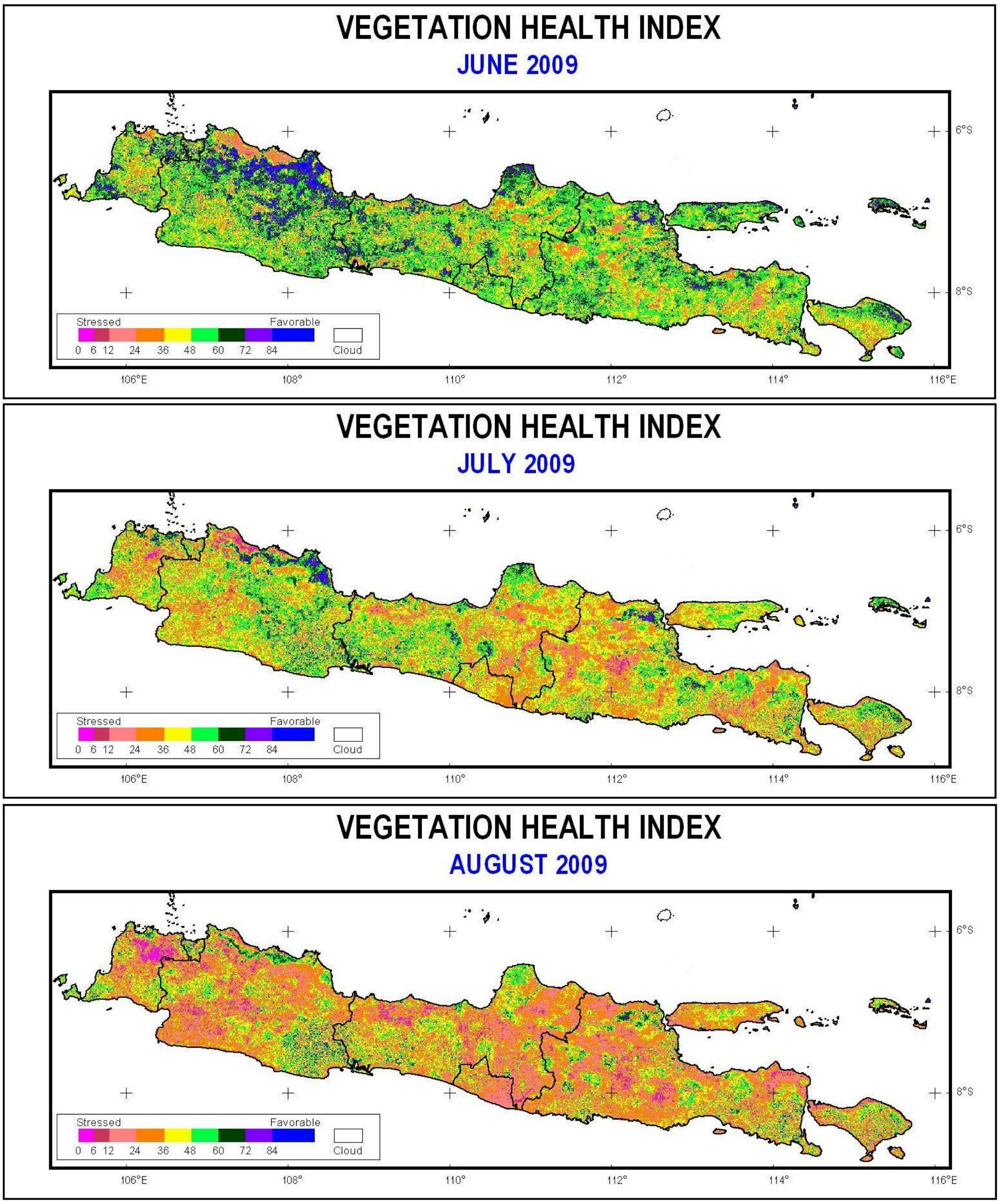

Figure 4-5: VHI distribution in Java island for a) June 2009, b) July 2009, and c) August 2009

5 CONCLUSIONS

The utilization of satellite remote sensing data to produce the SPI, VCI, TCI, and VHI as sources of information about the meteorological and agricultural drought-vulnerable areas has been evaluated for Java island in the period of June-August 2009 ENSO event. Some of the advantages of using the satellite remote sensing data are their consistency, multi-temporal coverage of large areas in real-time and at frequent intervals, mapping at a regular spatial resolution, and cost-effective.

The SPI distribution shows that Java island has experienced the mild to moderate meteorological drought since June 2009. In August 2009, the intensity of the meteorological drought reached moderate for most of Java island. The time-series of VCI from June to August 2009 show that the vegetative stress due to the moisture vegetation has developed from East Java to West Java. On the other hand, the TCI maps show that vegetative stress due to the temperature condition has developed from East Java to West Java. Consequently, the vegetation drought conditions derived from the VHI maps show that in June and July 2009 a decreased of drought intensity occurred from western and eastern Java island resulted in moderate to severe vegetative stress condition in August 2009.

From some results above, it also could be concluded that the vegetative drought neither follows any spatio-temporal pattern nor shows a linear relationship with meteorological drought. Therefore, there is no direct the relationship between rainfall, VCI, TCI, and VHI. Finally, further research should be conducted, particularly in validating the indices with the condition in the fields and extending the time period of observation.

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