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Dini Daruati
Departement of Geography, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Depok 16424, Indonesia, dini_daru@yahoo.com

Rahmatulloh Rahmatulloh
Departement of Geography, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Depok 16424, Indonesia

Sri Hardiyanti Purwadhi
Departement of Geography, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Depok 16424, Indonesia

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Dini Daruati*, Rahmatulloh, and Sri Hardiyanti Purwadhi

Departement of Geography, Faculty of Mathematics and Natural Sciences,
Universitas Indonesia, Depok 16424, Indonesia

*E-mail: dini_daru@yahoo.com

Abstract

This study examines agricultural drought paddy fields in West Java. The aims of this research are to know the pattern and distribution of paddy field drought in West Java and the correlation between drought and the physical characteristics. The agricultural drought is obtained from TVI (Thermal Vegetation Index) model. TVI is derived from MODIS Terra satellite image, which is the ratio between the LST (Land Surface Temperature) and EVI (Enhanced Vegetation Index). Physical factors studied are rainfall, l slope, geomorphology, soil drainage, and irrigation areas. The most severe drought occurred in September 2006 because of El Nino, covering 806,564 ha, and distributed in almost all West Java Province while the lowest occurred in September 2010 because of La Nina, covering 101,959 ha, and mostly distributed in Subang and Indramayu district. Spatial distribution of drought in 2000-2011 has the same pattern. At the start of the dry season (May) drought occurred in the north (along the coast) then expanded to the east / south in the middle of the dry season (July-August) and then increased further to the west at the end of the dry season (September). Incidence of drought has correlation with the physical condition of the area, but the most influential is the rainfall based on Chi-square test.

Abstrak

Pola Kekeringan Pertanian di Jawa Barat Menggunakan Indeks Vegetasi Termal dari Satelit Modis-Terra. Penelitian ini mengkaji kekeringan pertanian lahan sawah di Provinsi Jawa Barat. Tujuan penelitian ini adalah untuk mengetahui sebaran wilayah dan pola kekeringan pertanian lahan sawah yang terjadi di Provinsi Jawa Barat dan untuk mengetahui hubungan kekeringan pertanian lahan sawah dengan karakteristik fisik lahannya. Kekeringan pertanian diperoleh meggunakan model *thermal vegetation index* (TVI) dari pengolahan citra satelit MODIS Terra tahun 2000-2011. TVI merupakan rasio antara *land surface temperature* (LST) dan *enhanced vegetation index* (EVI). Faktor fisik yang dikaji adalah curah hujan, kemiringan lereng, geomorfologi, drainase tanah, dan wilayah irigasi. Hasil yang didapatkan adalah kekeringan sangat berat tertinggi terjadi pada bulan September 2006 dengan luas 806.564 ha yang meliputi hampir seluruh Provinsi Jawa Barat karena pengaruh El Nino, sedangkan terendah terjadi pada bulan September 2010 dengan luas 101.959 ha yang sebagian besar berada di Kabupaten Subang dan Indramayu karena pengaruh La Nina. Sebaran kekeringan pada tahun 2000-2011 memiliki pola yang sama yaitu pada awal musim kering (Mei) kekeringan terjadi di bagian utara (sepanjang Pantura) kemudian bertambah luas ke arah timur/selatan pada pertengahan musim kering (Juli-Agustus) lalu bertambah lagi ke arah barat pada akhir musim kering (September). Kejadian kekeringan memiliki hubungan dengan kondisi fisik wilayah. Akan tetapi, berdasarkan uji ststistik *Chi-square* faktor yang paling berpengaruh adalah curah hujan.

Keywords: agricultural drought, EVI, LST, MODIS, TVI

1. Introduction

Drought is a natural disaster that occurred almost every year in Indonesia as a tropical country. This is because the drought is closely associated with water availability for the necessities of life, agriculture, economic and environmental activities. According to Jayaseelan [1], drought is divided into meteorological drought, hydrological drought, and agricultural drought. Agricultural drought is one of the issues that threaten food security in Indonesia. In addition, Indonesia is located between two oceans causing climate of

Indonesia to be affected by the climatic phenomenon caused by the movement of the surface temperature Indian Ocean and Pacific Ocean. Both activities of the movement of the sea surface temperature resulted in two phenomena. They are climate positive Indian Ocean Dipole and the El Nino. El-Nino will occur when warmer waters in the central Pacific and eastern raise the temperature and humidity of the atmosphere above. This incident led to the formation of clouds that will enhance precipitation in the surrounding area. The western part of the Pacific Ocean causes air pressure increased growth inhibition clouds over the oceans in eastern Indonesia, so that in some parts of Indonesia a decline in rainfall is far from normal. While La Nina is the opposite of El Nino, which causes the air pressure in the equatorial western Pacific to decrease, more to the west than normal, causing the formation of the cloud and heavy rain in the surrounding area [2].

West Java is 'Production House' for the economy of Indonesia; the agriculture sector contributes 15% of the total value. Almost 23% of the total area of 29.3 thousand square kilometers is allocated to production. Unfortunately in August 2011 some 17,000 hectares of paddy crop failure due to drought happened mostly in areas out of reach of irrigation and resulted in about 200 acres of crop failure. The incident also occurred in previous years, as in 2006, crop failure reached 48, 016 hectares while drought affected area reached 118,076 hectares. Drought occurred in 17 districts in West Java, including Cirebon, Indramayu, Subang, Tasikmalaya, Bandung and Garut (Agriculture Ministry, 2011).

Remote sensing techniques have been widely used for providing spatial data source because it covers the surface of the earth that is spacious and has a high temporal resolution. Therefore it is relevant for the monitoring of large areas. According to Ruud Hurkmans *et al*. [3], every kind of object of vegetation will provide vegetation index values according to their characteristics. On the surface of the land that has high levels of vegetation index, the changes of land surface temperature (LST) are not so obvious because the vegetation was able to regulate the water. The relationship between LST and vegetation index is negative, which means that the higher the surface temperature the lower the vegetation index [4].

Sandholt *et al*. [5] used the hydrological drought index in the model that produces dryness correlation between the Temperature Vegetation Index (TVDI) and root zone soil moisture using AVHRR imagery. In another case, agricultural drought patterns in Java Island reviewed by Suseno [6] used NOAA-18 AVHRR imagery with the triangle method, while the drought monitoring to anticipate forest fires studied by Parvati and Suwarsono [7] used the TVDI model from MODIS-Terra satellite. Dede Dirgahayu [8] also used MODIS-Terra satellite to analyze drought pattern. Thermal Vegetation Index (TVI) model is used, which is the ratio between the LST and Enhanced Vegetation Index (EVI), to monitor agricultural drought conditions in the district of Indramayu. Therefore, this model needs to be reviewed in this study for accuracy over a wider area, the entire province of West Java.

In this study, the model TVI was built to access the distribution and patterns of agricultural drought of West Java in 2000-2011 then linked to the physical characteristics of the region to determine the association. Long period of records study was necessary to determine the existence of extraordinary events that influenced global climate such as the El Nino and La Nina.

2. Methods

The research was conducted in West Java Province, geographically located between 5 ° 50 '- 7 ° 50' S and 104 ° 48 '- 108 ° 48 East. Distribution of wetland paddy field agricultural drought in West Java was obtained from MODIS-Terra satellite data (years 2000-2011) extraction using the TVI.

MODIS Terra satellite has 36 bands and 3 spatial resolutions. The spatial resolutions are: 250 m (bands 1-2), 500 m (bands 3-7), 1000 m (bands 8-36). In this study the spatial resolution is 500 m. The MODIS data (LIB-8daily) is obtained from LAPAN and downloaded from NASA website.

$$EVI = 2.5*(\rho 2 - \rho 1)/(1 + \rho 2 + 6*\rho 1 - 7.5*\rho 3) \quad (1)$$

Where:
$\rho 1,2,3$ = reflectance of *Red, NIR*, dan *Blue band*

Information related to temperature can be obtained from the data of LST, which is calculated based on a formula set forth in the Algorithm Theoretical Basis Document (ATBD) [9]. The formula is:

$$LST = T_{31} + 1.02 + 1.79*\Delta T + 1.2*\Delta T^2 + (34.83 - 0.68*WV)*(1 - \varepsilon) + (5.19*WV - 73.27)*\Delta\varepsilon - 273 \quad (2)$$

Where:
$T_{31,32}$ = Brightness temperature of 31and 32 band
ΔT = T_{31} - T_{32}
WV = *water vapour*
E = $0.971 + 0.018*f_v^2$ is average emissivity of land surface
$\Delta\varepsilon$ = $[0.006*(1 - f_v)]^2$
f_v = (EVI – EVI min)/(EVI max – EVI min)

Furthermore, the value of LST and EVI 8 daily was used to obtain the monthly mean LST and EVI values in May-September years 2000-2011. Then do the

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Tabel 1. TVI Values

Drought Class	TVI
Mild	55–70
Medium	71–85
Severe	85–99
Very Severe	>99

Source: Dirgahayu, 2006 [8]

calculation of TVI, which is the ratio between the LST and EVI (Table 1). TVI is a value that describes the paddy crop drought conditions; to be performed is as follows [8]:

$$TVI = LST/EVI \quad (3)$$

The physical condition used for analysis is represented by maps of rainfall, topography, soil drainage, geomorphology, and irrigation area. That maps then overlay with the drought map (TVI map).

Rainfall data (mm/month) are from monthly TRMM images (source: LAPAN), then created to be isohyet map. Slope map is derived from DEM SRTM data resolution of 90 m downloaded from the USGS website. Soil drainage data is from map of soil types obtained from The Centre of Soil Research (Puslitan) then classified again based on the ability to pass and store water. The map is also compared with the Land System Map of Bakosurtanal (BIG). The geomorphological landforms origin is derived from the geomorphologic map (BIG). Irrigation area data source is from Water Resources Data Centre Ministry of Public Works.

Field survey was conducted on July 8 to 14, 2012 at 50 survey points distributed in Bogor, Karawang, Subang, Indramayu and Cirebon at origin of landforms volcanic, fluvial, marine, and structures in flat slope until steep. Field survey is using stratified random sampling method at the level of drought.

3. Results and Discussion

Drought pattern 2000-2011. May was dominated by mild drought except in 2007, 2009, and 2010. The severe drought occurred in May of 2009 that is 469,800 ha or about 39% of total rice fields in West Java. Rice field drought that occurred in May is affected by the physical factors because rainfall is mostly above 100 mm/month. Drought always occurred in the north coast (most of Bekasi, Karawang, Subang, Indramayu, and Cirebon district). The physical conditions of that area are as follows: slope $<1^0$, flood plains, coastal marsh basin, alluvial plains, and tidal plains landforms, partially have irrigation, soil drainage moderate hampered until severely hampered, soil type *Tropaquept*. This soil type generally has a high potential for erosion, growing from young alluvium in coastal waterways, has very shallow soil. In addition, the cause of drought in the north coast is the air temperature is higher than the central and southern part of the mountainous area, so the evaporation is higher.

Rice fields in June are still dominated by mild drought. The 2009 has the most widespread severe drought but more than in May, reaching 519.4 thousand ha or 43.6% of total rice fields in West Java. Rainfall in June varied, but relevant to the occurrence of drought. In 2008 and 2009 the drought was very severe in June because the rainfall is low, mostly below 100 mm/month. In the central part of West Java (Bandung regency), there are always areas of drought despite having high rainfall. The physical characteristics of the area is the slope of $<1^0$, no irrigation, lake alluvial landforms, moderate impeded drainage, soil type *Fluvaquents* that has a shallow soil and is easily eroded.

The most severe drought in July is in 2008, covering 57% of the rice fields in West Java, while in 2009 about 46%. Rainfall in July was slightly higher in 2002, 2004, 2005, and 2010. This is consistent with the incidence of drought, while the dominant is mild drought.

Drought in August is widespread in West Java, only 2005 and 2010 have rainfall >100 mm/month. Widest severe drought occurred in 2008, 2009, and 2003. Severe drought of 2008 reached 680,600 ha or 57% of the total rice fields in West Java, while the fewest occurred in 2002, which was only about 15% of the total rice fields in West Java. Severe drought in August 2003, 2008, and 2009 occurred in the northern part of Bekasi and Karawang, besides those years are not drought or mild drought. This is due to the following physical characteristics: a basin swamp coastal landforms from marine origin, so much longer to save water, slope $<1^0$, no irrigation, land drainage severely hampered, and soil type *Hydraquent* that has shallow groundwater.

Severe drought in September, with the order of the largest occurred in 2006, 2003, 2008, and 2009. The widest area reach 806,500 ha or about 67% of the total rice fields in West Java. The map can be seen on Figure 1. High rainfall in September occurred in 2005 and 2010, so the widest severe drought that year is in August and May. The narrowest severe drought occurred in September 2010 – the map can be seen on Figure 2. Drought in September in the year that affected El Nino (2003, 2006, 2008, and 2009) was distributed in almost all West Java, not excluding Ciamis and Tasikmalaya district that usually only have a mild drought. The graph of statistical area of drought in September 2000-2011 can be seen in Figure 3.

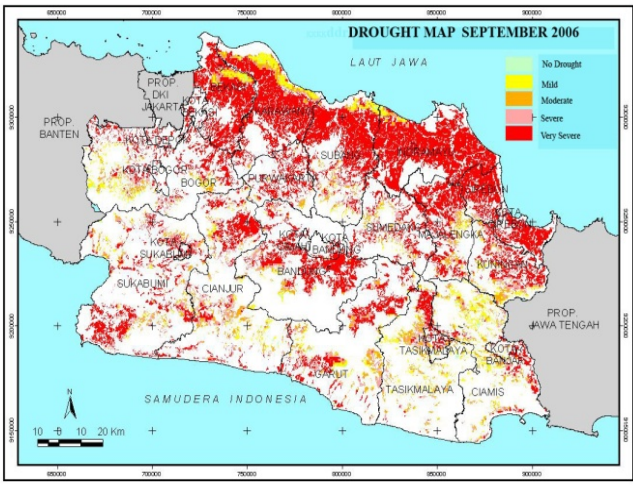

Figure 1. Drought Map in September 2006

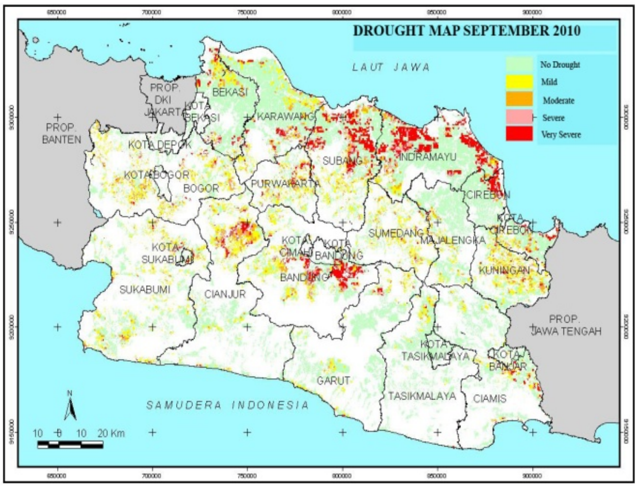

Figure 2. Drought Map in September 2010

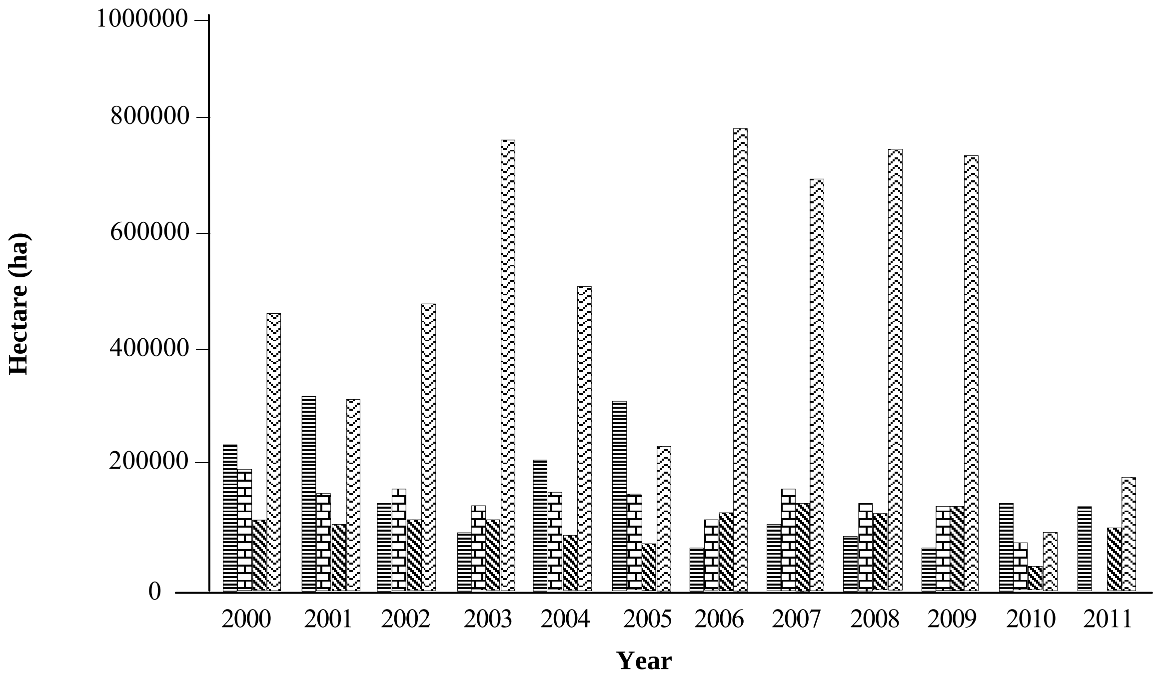

Figure 3. Graph of Drought Map in September 2000-2011; Mild ( ), Moderate ( ), Severe ( ), Very Severe ( )

The dynamics of spatial distribution of drought in 2000-2011 have the same pattern. At the start of the dry season (May), drought in the north (along the north coast) then moved toward increased drought east/south in mid-dry season (July) and then increased again to the west at the end of the dry season (September).

Correlation between drought and physical condition. To determine the correlation between drought and the physical conditions of the area, spatial analysis (overlay) and statistical analysis (chi-square) are used.

The physical characteristics of the most drought areas are presented in Table 2. Areas that have very severe levels of drought are most likely to occur when rainfall is low and at areas with flat slope, good soil drainage until slightly hampered, no irrigation, and the origin of fluvial landforms. These areas are part of Subang, Indramayu and Cirebon districts. Moderate to severe dryness occurs at much lower rainfall, gentle slope, good soil drainage, irrigation unaffordable, and the volcanic landforms. Areas that have such characteristics are partially District of Sumedang, Majalengka, Kuningan,

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Table 2. Physical Characteristic of Drought Area

Drought Level	Rainfall (mm/bln)	Slope (o)	Soil Drainage	Irrig	Geomorph
No Drought	101-200	<1	Slightly impeded	Yes	Fluvial
Mild	51-100	<1	Well	No	Vulkan
Moderate	51-100	3-6	Well	No	Vulkan
Severe	51-100	3-6	Well	No	Vulkan
Very Severe	0-50	<1	Well & Slightly impeded	No	Fluvial

Table 3. Correlation of Drought and Rainfall (ha)

Rainfal Drought	0-50 mm/mt	51-100 mm/mt	101-200 mm/mt	201-400 mm/mt	>400 mm/mt
No Drought	10,650	12,812	12,430	0	0
Mild	52,393	72,695	73,114	0	0
Moderate	103,907	109,832	89,883	0	0
Severe	101,322	100,943	64,798	0	0
Very Severe	778,512	487,484	291,308	0	0

Tasikmalaya, Garut, Bogor, and Sukabumi, while the region that has a mild dryness are common in areas with the characteristics of low rainfall, flat slope, well drained, no irrigation, and the origin of volcanic landforms. The areas are distributed in Majalengka, Tasikmalaya, and Garut districts.

Based on statistical tests, p-value = 0 is less than α = 0.05, it can be concluded that the level of dryness is correlated with the level of rainfall. The correlation of drought and rainfall can be seen at Table 3, while the results of Chi-Square test at Table 4. *Spearman Correlation* is negative value, so that it can be stated that the relationship between drought and rainfall levels are inversely proportional. The higher the rainfall rate, the lower the level of dryness.

Correlation between agricultural drought and slope are described at Table 5, while the statistical test can be seen at Table 6. The degree of dryness and the slope is inversely proportional. The higher the dryness level, the lower the slope. This is evident as observed during the field survey conducted in July 2012. Severe drought is mostly common around the north shore which have flat slope, whereas the mild drought mostly occurs in high slope that is usually located in mountainous regions such as Bogor. This phenomenon can be explained that flat areas mostly have higher temperature and evaporation than mountainous area.

In West Java, most of the soil has good drainage but the north is dominated by fairly impeded drainage. Soil drainage is closely related to the type of soil class although at the same level of drainage there are several different types of soil. In Table 7 it can be seen that in every class drainage the area increases with increasing levels of drought that indicate there is a relationship, and it is evident from the results of *Chi-Square* test (Table 8).

Most landforms in West Java originated from volcanic landforms, structures, and fluvial. In mild to severe droughts occurred, most are commonly originated from volcanic landforms, while the very severe drought occurred originated from fluvial landforms. In each class drainage, the frequency of occurrence increases with the level of dryness. In general, drought will be more potential on the type of soil that has rapid drainage, however in west java drought is most likely to occur on the well drainage into slightly impeded area. The correlation between drought and geomorphology can be seen at Table 9, while the result of *Chi-Square* tests at Table 10.

Table 4. Chi-Square Test of Drought and Rainfall

	Value	df	Asymp.Sig. (2-sided)
Pearson Chi-Square	79496.687[a]	8	0
Likelihood Ratio	79019.814	8	0
Linear-by-Linear Association	74748.763	1	0
N of Valid Cases	2362083		
Contingency Coefficient	0.588		
Spearman Correlation	-0.129		

Table 5. Correlation of Drought and Slope (ha)

Slope Droughtt	$<1^0$ Flat	$1\text{-}3^0$ Very Gentle	$3\text{-}6^0$ Gentle	$6\text{-}9^0$ Slightly Steep	$9\text{-}25^0$ Steep	$25\text{-}65^0$ Very Steep
No Drought	24,705	2,908	1,848	2,529	3,638	371
Mild	57,235	23,657	39,112	36,312	40,118	2,061
Moderate	45,427	59,079	75,213	60,564	61,282	2,361
Severe	41,561	63,628	65,308	49,507	45,662	1,625
Very Severe	819,978	381,217	175,201	100,279	80,260	2,300

Table 6. Chi-Square Test of Drought and Slope

	Value	df	Asymp.Sig. (2-sided)
Pearson Chi-Square	415720.663[a]	20	0
Likelihood Ratio	427645.261	20	0
Linear-by-Linear Association	226640.241	1	0
N of Valid Cases	2364946		
Contingency Coefficient	0.387		
Spearman Correlation	-0.355		

Table 7. Correlation of Drought and Soil Drainage (ha)

Soil Drainage Drought	Fast	Slightly Fast	Good	Slightly Hampered	Hampered	Very Hampered
No Drought	357	787	8,150	24,537	262	1,717
Mild	640	19,771	110,441	58,701	2,691	200
Moderate	614	42,514	202,181	37,928	6,415	1,158
Severe	572	34,582	183,418	28,783	8,998	1,107
Very Severe	2,567	106,891	662,744	644,717	99,546	10,971

Table 8. Chi-Square Test of Drought and Soil Drainage

	Value	df	Asymp.Sig. (2-sided)
Pearson Chi-Square	239569.123[a]	20	0
Likelihood Ratio	256656.150	20	0
Linear-by-Linear Association	60512.270	1	0
N of Valid Cases	2303960		
Contingency Coefficient	0.307		
Spearman Correlation	0.266		

Table 9. Correlation of Drought and Geomorphology (ha)

Drought Geomorphology	No Drought	Mild	Moderate	Severe	Very Severe
Denudasional	508	297	74,960	124,969	95,861
Fluvial	14,256	16,438	7,389	13,508	14,718
Fluvial Lake	0	41,498	34,588	37,451	97,108
Fluvial Volcano	1	457	31,891	27,550	679,417
Marine	307	3,644	3,106	4,856	64,035
Solusional	12,592	18,959	9,142	15,771	87,377
Structural	137	1,539	10,807	7,906	105,316
Structural denudasional	0	0	2,526	2,077	15,679
Volcano	1,179	32,715	71,507	59,370	177,210
Volcano denudasional	6,763	10	618	1,338	9,662

Drought mostly occurs in the non-irrigated area, such as in the coastal regions. Although irrigation plays an important role in overcoming the drought, but if the dry season lasts too long, water for irrigation is not sufficient to keep the agricultural grows well. One solution to overcome the problem is to create dams that have reasonably high capacity and are spread throughout West Java so that it can be storage of water in the dry season. More importantly, there is a rotation time of planting and crop rotation schedule so that water flow can be fairly distributed.

From Table 11 it can be seen that each level of drought has a larger area of no irrigation. To determine whether there is correlation, it can be seen from the results on the *Chi-Square* test in Table 12. It can be concluded that there is a correlation between the drought with irrigation areas because it has p-value = 0 is less than $\alpha = 0.05$. Drought is more common in areas that are not irrigated fields. In the north coast areas, severe drought with no irrigation is wider than with irrigation.

To determine the physical characteristics of the most influential of drought, it can be seen from the value of the *Contingency Coefficient* (CC) with *Chi-Square* test between drought and each variable. The greater the CC value of variable, the greater influence of variable to drought. The results of CC using *Chi-Square*-Test can be seen in Table 4, 6, 8, 10, and 12.

Physical characteristic that mostly affects the drought is rainfall. This can be seen in Table 4. Rainfall has a highest value of *Contingency Coefficient* (CC) compared to other physical parameters, it is 0.588.

Table 10. Chi-Square Test of Drought and Geomorphology

	Value	df	Asymp.Sig. (2-sided)
Pearson Chi-Square	1.075E6	36	0
Likelihood Ratio	864548.959	36	0
Linear-by-Linear Association	396.375	1	0
N of Valid Cases	2039013		
Contingency Coefficient	0.180		
Spearman Correlation	-0.179		

Table 11. Correlation of Drought and Irrigation (ha)

Irrigation Drought	Irrigation	No Irrigation
No Drought	20,787	15,447
Mild	56,830	141,722
Moderate	56,687	247,289
Severe	50,830	216,500
Very Severe	577,936	981,913

Table 12. Chi-Square Test of Drought and Irrigation

	Value	df	Asymp.Sig. (2-sided)
Pearson Chi-Square	75283.317[a]	4	0
Likelihood Ratio	78867.383	4	0
Linear-by-Linear Association	17787.289	1	0
N of Valid Cases	2365941		
Contingency Coefficient	0.176		
Spearman Correlation	0.123		

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Slope has the second effect after rainfall with CC value 0.387, then the soil drainage with a value of CC 0.307. Geomorphologic and irrigation factors are the last factors that affect the drought based on this statistic test. This is due largely to rice field wetland being located on the same geomorphologic unit, which is the origin of fluvial landforms, while irrigation covers only a small research area.

Field survey was conducted on July 8 to 14, 2012. The aim of field survey is to determine the condition of drought field that matched with the MODIS satellite image on the same date. It is necessary to validate the model. Model validation was performed to determine whether the models are close to the reality or not. In this study, model validation is obtained by comparing the image of MODIS land surface temperature (LST) and drought level with the LST value and drought level in the field. EVI values were also verified in the field and can be used to validate the model although only qualitatively.

The results of linear regression between LST value that measured in field and LST MODIS Image is 72.2%, while the result of linear regression between the level of dryness in the field and MODIS Image is 78.8%. According to Congalton, 2001 [10], the results of both are moderate correlation so that the model is considered good enough. Thermal Vegetation Index (TVI) model using MODIS-Terra Satellite can represent actual drought on the ground.

4. Conclusions

Based on these results it can be concluded that the highest very severe drought occurred in September 2006 covering an area of 806,564 ha which includes almost all of West Java Province, due to the influence of El Nino, while the lowest occurred in September 2010 covering an area of 101,959 ha, mostly located in the district of Subang and Indramayu due to the influence of La Nina.

The dynamics of spatial distribution of drought in 2000-2011 have the same pattern. At the start of the dry season (May) drought in the north (along the north coast), then drought expanded to the east / south in the middle of the dry season (July-August) and then increased further to the west at the end of the dry season (September) based on the processing of spatial data using the model of TVI.

Incidence of drought is affected by the physical condition of the rainfall, slope, soil drainage, irrigation, and geomorphology, but the most influential is the rainfall based on the value of the contingency coefficient (CC) which is 0.588 using *Chi-Square* test.

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