Monitoring 2015 drought in West Java using Normalized Difference Water Index (NDWI)

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Abstract. Drought is a slow developing phenomenon that accumulates over period and affecting various sectors. It is one of natural hazards that occurs each year, particularly in Indonesia over Australian Monsoon period (June to August) [2]. During drought event, vegetation’s cover can be affected by water stress. Normalized Difference Water Index (NDWI) is a method for water resource assessment and known to be strongly related to the plant water content. NDWI is produced from MODIS bands Near-infrared (NIR) and Short Wave Infrared (SWIR). This research aims to monitor drought using NDWI in West Java during El Niño 2015 and its impact on rainfall variability. The result showed rainfall was decreased significantly starting from May-June, then increased in November. According to NDWI, it also showed that mostly West Java Region affected by drought during May-November. Very strong drought occurred on September-November. On December, areal extent of drought was decreasing significantly because rainfall had increased during November. Generally, areal extent of drought in West Java was dominated by strong and moderate drought. It implied that El Niño 2015, give great impact on increasing drought and decreasing rainfall in West Java. NDWI can be detected drought occurrence as it have good correlation with rainfall spatially.

1. Introduction
Drought is a slow developing phenomenon that accumulates over period and affecting various sectors (i.e. economy, agriculture, etc.) [1]. It is one of natural hazards that occurs each year, particularly in Indonesia over Australian Monsoon period (June to August) [2]. During drought event, vegetation’s cover can be affected by water stress. It can be lead to crop failure and agricultural production might be decreased. Early mitigation by using near-real time information on plant water stress can be used as early warning system to minimize the drought impact. Therefore, drought assessment can be used for drought monitoring in a quick and cost-effective way to increase adaptability of water retention. One of common methods for drought monitoring is by using satellite based indices in which has proven to be an effective way and an easy tool from previous study [3-4].

The Normalized Difference Water Index (NDWI) is a method for analyzing data for water resource assessment [5]. NDWI had a quicker response to drought conditions than NDVI [1] and it is known to be strongly related to the plant water content. NDWI is produced satellite bands Near-infrared (NIR) and Short Wave Infrared (SWIR). NIR reflectance is affected by leaf internal structure and leaf dry matter content but not by water content while SWIR reflectance reflects changes in both the vegetation water content and the spongy mesophyll structure in vegetation canopies. These two combination
remove variations induced by leaf internal structure and improving the accuracy in retrieving the vegetation water content [6]. NDWI is a remote sensing based indicator sensitive to the change in the water content of leaves [7].

The occurrence of El Niño event in 2015 was impacting rainfall variability in Indonesia and triggered more severe drought to be happened [4]. West Java has potentially great contribution to food security in Indonesia. Climate in West Java is strongly influenced by monsoon (Asian and Australian monsoon) and ENSO phenomena, such as El Niño and La Niña. Analysis of rainfall variability during El Niño and La Niña has been conducted in West Java and resulted a good correlation [8]. Thus, this research aims to monitor drought using Normalized Difference Water Index (NDWI) in West Java during El Niño year 2015 and its impact on rainfall variability.

2. Methods

2.1. Study area

West Java is located at 5°50’–7°50’ S and 104°48’–108°48’ E (figure 1) with an area of 35,377.76 km² [9]. It covers 18 districts and 9 cities. The temperature ranges between 9°C in the Peak of Pangrango Mountain to 30°C in North Coast. The average rainfall is 2,000 mm per year but in some mountainous areas might reach 3,000 to 5,000 mm per year.

![Figure 1. Geographical map of West Java Region.](image)

2.2. Data background and processing

In this study, NDWI was calculated from NIR and SWIR band spectral of MODIS satellite data, namely MOD09A1 datasets. MOD09A1 provides MODIS band 1-7 surface reflectance 8-day at 500 m resolution [10]. These data were available and obtained from https://ltdaac.usgs.gov. NIR reflectance was retrieved from MOD09A1 surface reflectance band 2 products (841-876 nm), while SWIR from surface reflectance band 7 products (2,105-2,155 nm). The 8-day NIR and SWIR were composited into month from January to December 2015. NDWI then calculated using following equation (equation 1) and classified into eight categories (table 1) based on Gulacsi and Kovaks [11]. CHIRPS (Climate Hazards Infrared Precipitation with Stations) data were used for analyzing rainfall variability in West Java during El Niño year 2015 spatially. Rainfall data were obtained from IRI/LDEO Climate Data Library.
\[ NDWI = \frac{NIR - SWIR}{NIR + SWIR} \]  

Table 1. Drought category of NDWI [11].

| Category                  | Values         |
|----------------------------|----------------|
| Very High Moisture Content | NDWI ≥ 0.7     |
| High Moisture Content      | 0.6 ≥ NDWI > 0.7 |
| Moderate Moisture Content  | 0.5 ≥ NDWI > 0.6 |
| Low Moisture Content       | 0.4 ≥ NDWI > 0.5 |
| Weak Drought               | 0.3 ≥ NDWI > 0.5 |
| Moderate Drought           | 0.2 ≥ NDWI > 0.3 |
| Strong Drought             | 0 ≥ NDWI > 0.2  |
| Very Strong Drought        | NDWI < 0       |

3. Result and discussion

3.1 Spatial analysis of monthly rainfall data
Rainfall in Indonesia is influenced by various climate variability, namely IOD, ENSO, Monsoon, and MJO. One of them, El Niño, has high impact on decreasing rainfall in Indonesia including West Java. The type of rainfall in West Java is monsoonal that has two season, dry and wet season. Dry season usually occurs on June, July, August (JJA), while wet season on December, January, and February.

During El Niño 2015, decreasing rainfall was significant. In northern West Java, decreasing of rainfall was starting from May, while in the southern part of West Java decreasing of rainfall was starting from June (figure 2). From June to October, the rainfall was below 60 mm/month in southern part of West Java and below 30 mm/month in northern part of West Java. Rainfall in northern part of West Java mostly lower than the other area. On November, rainfall in southern West Java increased up to 300 mm/month (figure 2). This increasing rainfall on November can caused by Monsoon Asia [12].

3.2 Monitoring of drought
Drought is an effect of deficit rainfall in some period of time [3]. El Niño in 2015 given specific impact on water availability in West Java Province. NDWI on this study used to identify drought based on plant water content. West Java Province is one of central rice production in Java Island, therefore monitoring and understanding drought based on plant water content is important to be carried out.

According to NDWI, almost all region in West Java was affected by drought in 2015 (figure 3). Weak to moderate drought already occurred on January in some area of West Java. From January to July, total area and severity of drought did not increase. During this period, severe drought occurred in central and northwest of West Java such as Bekasi, Bogor, Indramayu, Subang, and Cirebon. Data from Department of Agriculture in West Java Province also shown that one of region in North West Java, namely Indramayu, experienced drought with high areal extent [13].

During August 2015, area of drought increased significantly. Almost all region experienced drought. Low moisture content to moderate drought dominance occurred in southern West Java, while in the opposite region was dominated by strong to very strong drought. During September, areal extent of very strong drought increase. It is occurred due to accumulation of the decreasing rainfall in West Java region. Very strong drought on September continued to November. On December, area of drought decreased significantly, particularly in southern area of West Java Province. It occurred because rainfall had increased during November.

Rainfall deficit and drought in West Java Province did not occur at the same time. There was a lag time between one to three months. Wang et al. [1] also point out that there was a lag time between deficit
rainfall and drought around three month on crop production and six month on forest. The lag time occurred because soil water content did not reduce directly when rainfall gradually decreased [14].

Figure 2. Spatial rainfall of West Java Province in 2015.
3.3 Areal extent of NDWI in percentage

Severity and area of drought in West Java increased during August to November 2015 (figure 3). Therefore we analyze areal extent for every level of drought during this period. On August, moderate moisture content dominantly occurred with percentage 23.41% (table 2). Strong and very strong drought cover around 17% area of West Java. During September, strong and very strong drought dominantly occurred. This condition was caused by accumulation of deficit rainfall from June to August. Severity of drought decreased during October. High moisture content was dominant in this month. During November, area of strong and very strong drought increased again around 25%. Generally, areal extent of drought in West Java was dominated by strong and moderate drought. It implied that El Niño in 2015, give great impact on increasing drought in West Java.

Figure 3. NDWI spatial map 2015 of West Java Province.
4. Conclusion
The occurrence of El Niño event in 2015 was impacting rainfall variability and drought in West Java. During El Niño 2015, rainfall decreased significantly starting from May to June in all over West Java region approximately 60 mm/monthly in southern part and 30 mm/monthly in northern part of West Java. Then, rainfall increased up to 300 mm/month in November. According to NDWI as an index for drought monitoring, it also showed that mostly West Java Region affected by drought during May to November. Very strong drought occurred on September to November. On December, affected area of drought decreased significantly, particularly in southern part of West Java Province because rainfall had increased during November. Generally, affected area of drought in West Java was dominated by strong and moderate drought. It implied that El Niño in 2015, give great impact on increasing drought and decreasing rainfall in West Java. For drought monitoring, NDWI can be detected drought occurrence as it have good correlation with rainfall spatially.

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Table 2. Percentage of NDWI area.

| NDWI/ Month | Very strong drought | Strong Drought | Moderate Drought | Weak Drought | Low Moisture Content | Moderate Moisture Content | High Moisture Content | Very High Moisture Content |
|-------------|---------------------|----------------|------------------|--------------|----------------------|--------------------------|------------------------|--------------------------|
| Aug         | 2.78                | 14.18          | 12.46            | 13.73        | 11.95                | 23.41                    | 13.56                  | 2.84                     |
| Sep         | 4.28                | 22.76          | 13.77            | 18.76        | 18.18                | 14.67                    | 6.59                   | 1.15                     |
| Oct         | 0.66                | 4.28           | 21.32            | 0.00         | 29.44                | 0.00                     | 31.82                  | 12.35                    |
| Nov         | 1.16                | 24.45          | 21.31            | 19.31        | 16.97                | 11.54                    | 4.15                   | 1.23                     |

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