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Seasonal analysis of precipitation, drought and vegetation index in Indonesian paddy field based on remote sensing data

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Abstract. Paddy field is important agriculture crop in Indonesia. Rice is a food staple for 237,6 million Indonesian people. Paddy field growth is strongly influenced by water, but the amount of precipitation is unpredictable. Annual and interannual climate variability in Indonesia is unusual. In recent years remote sensing data has been used for measurement and monitoring of precipitation, drought and vegetation index such as Global Satellite Mapping of Precipitation (GSMaP), Multi-purpose Transmission SATellite (MTSAT) and Moderate Resolution Imaging Spectroradiometer (MODIS). The objective of this research is to investigate seasonal variability of precipitation, drought and vegetation index in Indonesian paddy field based on remote sensing data. The methodology consists of collecting of enhanced vegetation index (EVI) from MODIS data, mosaicking of image, collecting of region of interest of paddy field, collecting of precipitation and drought index based on Keetch Bryam Drought Index (KBDI) from GSMaP and MTSAT, and seasonal analysis. The result of this research has showed seasonal variability of precipitation, KBDI and EVI on Indonesia paddy field from 2007 until 2012. Precipitation begins from January until May and October until December, and KBDI begins to increase from June and peak in September only in South Sumatera precipitation almost in all month. Seasonal analysis has showed precipitation and KBDI affect on EVI that can indicate variety phenology of Indonesian paddy field. Peak of EVI occurs before peak of KBDI occurs and increasing of KBDI followed by decreasing of EVI. In 2010 all province got higher precipitation and smaller KBDI so EVI has three peaks such as in West Java that can indicated increasing of rice production.

1. Introduction

Paddy field is one of the important agriculture crops in Indonesia. Large of Indonesian paddy field around 8.06 million ha and total production around 65 million tons/year (<http://www.bps.go.id>). Indonesia is third country in the world which large rice-producing after China and India [1]. Growth in rice production is popularly perceived as the most important indicator of agricultural development in



Indonesia. Rice is the major crop for small farms, and the rice value chain is a key sector of the rural economy. Rice is also the food staple, and domestic demand for rice is very large. Historically, the thin world market for rice has meant that rice self-sufficiency was perceived as the key to ensuring national food security [2].

Phenology of paddy field can be characterized by three main periods: first the flooding and paddy transplanting period; second the growing period (vegetative growth, reproductive and ripening stages); and third the fallow period after harvest [3]. Many researchers mapping and monitor phenology of paddy field based on vegetation index derived from remote sensing data such as mapping paddy field in Southeast Asia [3], determining cropping type and cropping pattern of paddy field [4], multi sensor satellite data for rice production estimation [5], detecting rice phenology [6], global rice paddy field mapping [7] and Indonesian paddy field mapping [8]. Paddy field growing strongly influenced by water. In fact amount of precipitation is unpredictable. Annual and interannual climate variability in Indonesia is unusual. It is not homogenous over the whole region and coherence of precipitation patterns varies seasonally [9]. According Quint et al., [10] found that 93% of droughts in Indonesia between 1830 and 1953 occurred during El Niño years and four El Niño between 1973 and 1992. Information of precipitation and drought very important for transplanting period, harvest period and product estimation.

In recent years remote sensing has been used for measurement and monitoring precipitation and drought. According to Kubota et al., [11] Global Satellite Mapping of Precipitation (GSMaP) has been started since November 2002. The aims of the GSMaP are the development of an advanced microwave radiometer algorithm based on the deterministic rain-retrieval algorithm and the production of precise high-resolution global precipitation maps. And global Keetch Bryam Drought Index (KBDI) map based on precipitation derived from GSMaP and temperature from land surface temperature derived from Multi-purpose Transmission Satellite (MTSAT) has been generated [12]. The objective of this research to investigate seasonal variability of precipitation, drought and vegetation index in Indonesian paddy field based on remote sensing data. The methodology consists of collecting of enhanced vegetation index (EVI) from MODIS data, mosaicking of image, collecting of region of interest paddy field, collecting of precipitation and drought index based on Keetch Bryam Drought Index (KBDI) and seasonal analysis.

2. Methodology

Indonesia also called "Nusantara" is a country in Southeast Asia that is located on 6° N – 11° S and 95° E - 141° E, between the Asian and Australian continents and between the Pacific and Indian Oceans. Indonesia Consisting of 17,508 islands that is largest archipelagic country in the world. Indonesia have large area around 1.904.569 km² which population around 237,6 million people in 2012, total province is 33 province. (www.indonesia.go.id). For this study can see on the figure 1, we focus on six provinces that is West Java, East Java, North Sumatera, South Kalimantan, South Sulawesi and Papua. We choose their location because that location describes paddy field in each big island in Indonesia.

According to Indonesian statistical agency (<http://www.bps.go.id>) Indonesia paddy field in 2012 harvested area for whole Indonesia around 13 million ha with productivity 51.36 quintal/ha and total rice production around 69 million ton. The largest of harvested area in Java Island is 46% and the largest of rice production in Java Island is 53%. Out from Java such as North Sumatera, South Kalimantan and South Sulawesi have large harvested area and big rice production.

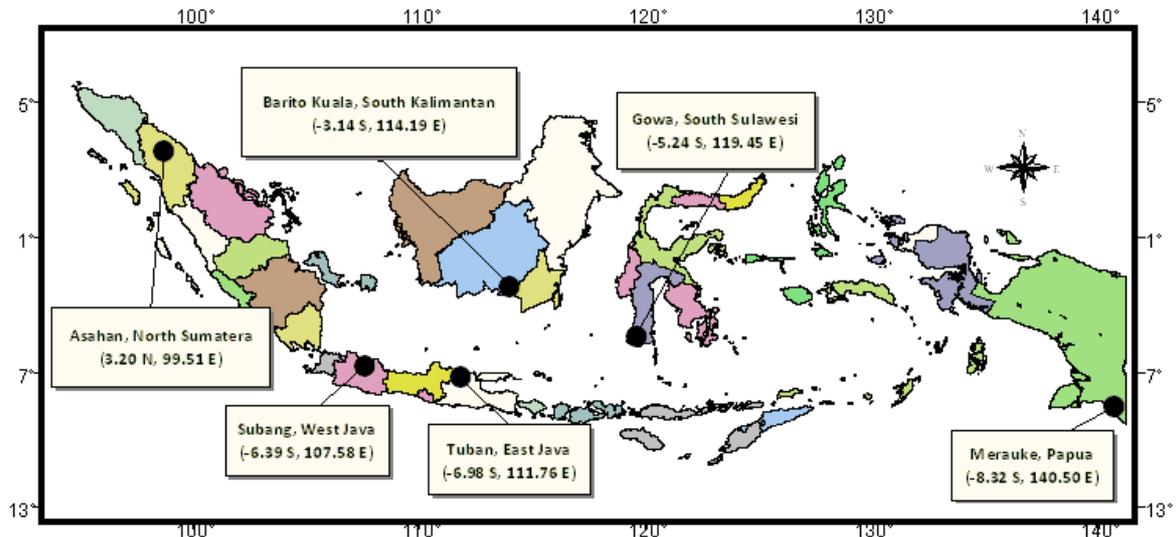


Figure 1. Case study focus on the six provinces in Indonesia.

In this research, methodology can see in the figure. 2. Methodology consists of collecting of enhanced vegetation index (EVI) from MODIS data, mosaicking of image, collecting of region of interest paddy field, collecting of precipitation and drought index based on Keetch Bryam Drought Index (KBDI) and seasonal analysis.

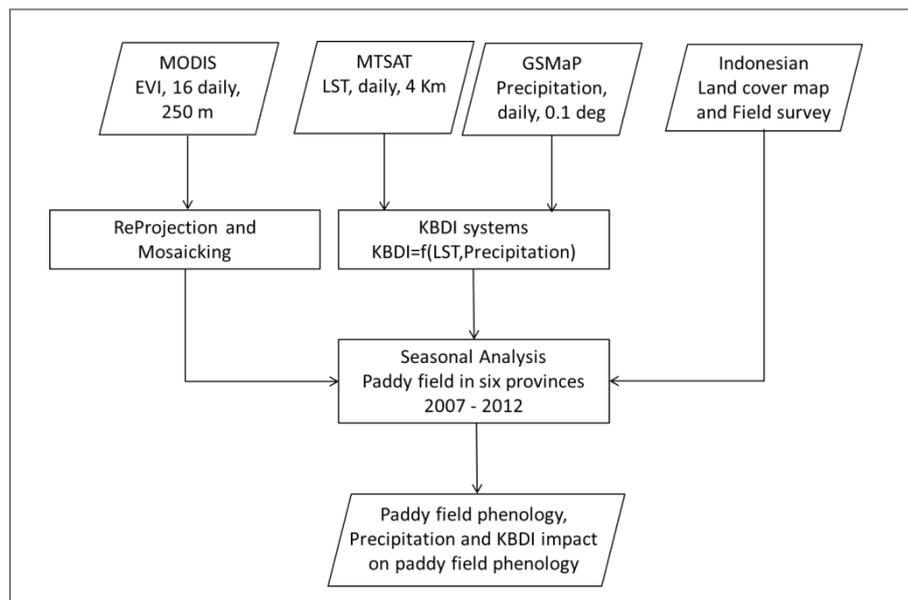


Figure 2. Methodology of seasonal analysis.

2.1 Enhanced Vegetation Index (EVI)

EVI was developed to optimize the vegetation signal with improved sensitivity in high biomass regions and improved vegetation monitoring through a de-coupling of the canopy background signal

and a reduction in atmosphere influences, the EVI equation follows [13]:

$$EVI = G\rho_{nir} - \rho_{prednir} + C_1 \times \rho_{pred} - C_2 \times \rho_{blue} + L \quad (1)$$

where ρ are atmospherically corrected or partially atmosphere corrected (Rayleigh and ozone absorption) surface reflectance, L is the canopy background adjustment that addresses nonlinear, differential NIR and red radiant transfer through a canopy, and C_1 , C_2 are the coefficients of the aerosol resistance term, which uses the blue band to correct for aerosol influences in the red band. The coefficients adopted in the EVI algorithm are, $L=1$, $C_1=6$, $C_2=7.5$, and G (gain factor)=2.5 [14].

EVI derived from global MODIS vegetation indices (MOD13Q1 product) which designed to provide consistent spatial and temporal comparisons of vegetation conditions. Global MOD13Q1 data are provided every 16 days at 250-meter spatial resolution as a gridded level-3 product in the Sinusoidal projection. Lacking a 250m blue band, the EVI algorithm uses the 500m blue band to correct for residual atmospheric effects, with negligible spatial artifacts (https://lpdaac.usgs.gov/products/modis_products_table/mod13q1). MODIS products are organized in a tile system with the Sinusoidal (SIN) projection grid, and each tile covers an area of 1200 km by 1200 km (approximately 108 latitude by 108 longitude at equator). Twelve tiles (H27V08, H27V09, H28V08, H28V09, H29V08, H29V09, H30V08, H30V09, H31V08, H31V09, H32V08, H32V09) are needed to cover the study area.

2.2 Precipitation and Keetch-Byram drought index (KBDI)

In this study precipitation derived from GSMaP. The GSMaP project was promoted for a study "Production of a high-precision, high-resolution global precipitation map using satellite data," sponsored by Core Research for Evolutional Science and Technology (CREST) of the Japan Science and Technology Agency (JST) during 2002-2007. Since 2007, GSMaP project activities are promoted by the JAXA Precipitation Measuring Mission (PMM) Science Team (http://sharaku.eorc.jaxa.jp/GSMaP_crest/). According to Prasetya et al., [15] monthly spatial average rainfall showed very good agreement between satellite monthly rainfall data and rain gauge data across Indonesia.

The Keetch-Byram drought index (KBDI) is a continuous reference scale for estimating the dryness of the soil and duff layers. The index increases for each day without rain (the amount of increase depends on the daily high temperature) and decreases when it rains. The scale ranges from 0 (no moisture deficit) to 800. The range of the index is determined by assuming that there is 8 inches of moisture in a saturated soil that is readily available to the vegetation [16]. The equation for computing the incremental rate of change of the index, ΔQ , is:

$$\Delta Q = 800 - Q \cdot 0.968 \exp(0.0486T - 8.30\Delta t \times 0.0011 + 10.88 \exp(-0.0441M)) \quad (2)$$

Where t is the daily maximum temperature, M the mean annual rainfall, Q the current KBDI, and ΔQ is a time increment set equal to 1 day [16]. In this study KBDI is generated by Institute of Industrial Science, The University of Tokyo (<http://webgms.iis.u-tokyo.ac.jp/KBDI/>) [12]. KBDI generated from precipitation derived from Global satellite mapping of precipitation (GSMaP) and temperature from land surface temperature derived from Multi-purpose Transmission SATellite (MTSAT). KBDI systems can monitor agricultural and climatological drought in 10km grid size on a daily basis [17].

According to Xanthopoulos et al., [18] a relationship between KBDI and plant water potential exists, the relation varies depending on the plant species.

2.3 Seasonal Analysis

We have collected region of interest (ROI) of rice paddy field area from whole province level Indonesia, size of ROI around 4x4 pixels. ROI based on land cover map from Indonesian Ministry of Forestry and Indonesian base map from Indonesian Information Geospatial Agency (BIG). We have mosaicked MODIS vegetation index for whole Indonesia from 2007 until 2012, and we have collected statistical KBDI and precipitation data from <http://webgms.iis.u-tokyo.ac.jp/DMEWS/plot.php> 2007 until 2012. Finally we have seasonal variability of vegetation index, precipitations and KBDI from 2007 until 2012 for whole province in Indonesia.

3. Results and Discussion

EVI derived from reprojection and mosaicking MOD13Q1 product. We have reprojected and mosaicked twelve tiles (H27V08, H27V09, H28V08, H28V09, H29V08, H29V09, H30V08, H30V09, H31V08, H31V09, H32V08, H32V09) to cover overall study area. Precipitation derived from GSMaP and Drought has been calculated from MTSAT and GSMaP. Precipitation, EVI and KBDI can see in the figure 3. We have plotted ROI of rice paddy field in six provinces, which are West Java, East Java, North Sumatera, South Kalimantan, South Sulawesi and Papua. And we got statistical seasonal variability of EVI, precipitation and KBDI.

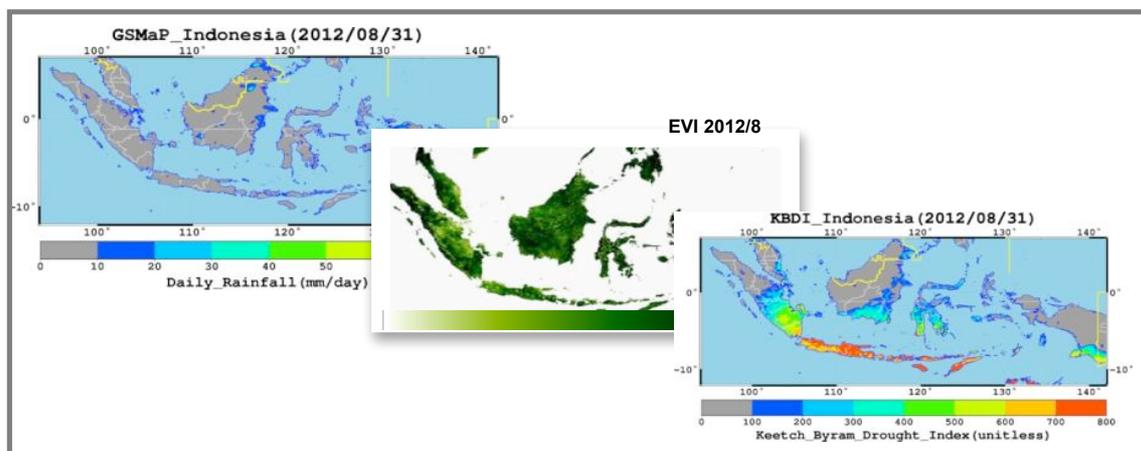


Figure 3. Precipitation, EVI and KBDI map in study area
(Derived from <http://webgms.iis.u-tokyo.ac.jp/DMEWS/Indonesia/>).

Statistical seasonal variability of EVI, precipitation and KBDI for six provinces in 2012 can see in the figure 4. According to figure 4 we can see seasonal variability of EVI in 2012 for six provinces. Seasonal variability of EVI shows of phenology of paddy field. EVI designed to enhance the contribution of vegetation properties and allow reliable spatial and temporal inter-comparisons of terrestrial photosynthetic activity and canopy structural variations [13]. Based on phenology of paddy field Lower EVI value that indicate flooding and rice transplanting period, and then EVI value increase until peak that indicate growing period (vegetative growth, reproductive and ripening stages), finally EVI value decrease that indicate fallow period after harvested. In this case EVI value have two

peak except South Kalimantan only one peak, it means in 2012 got two harvested and only in South Kalimantan got one harvested.

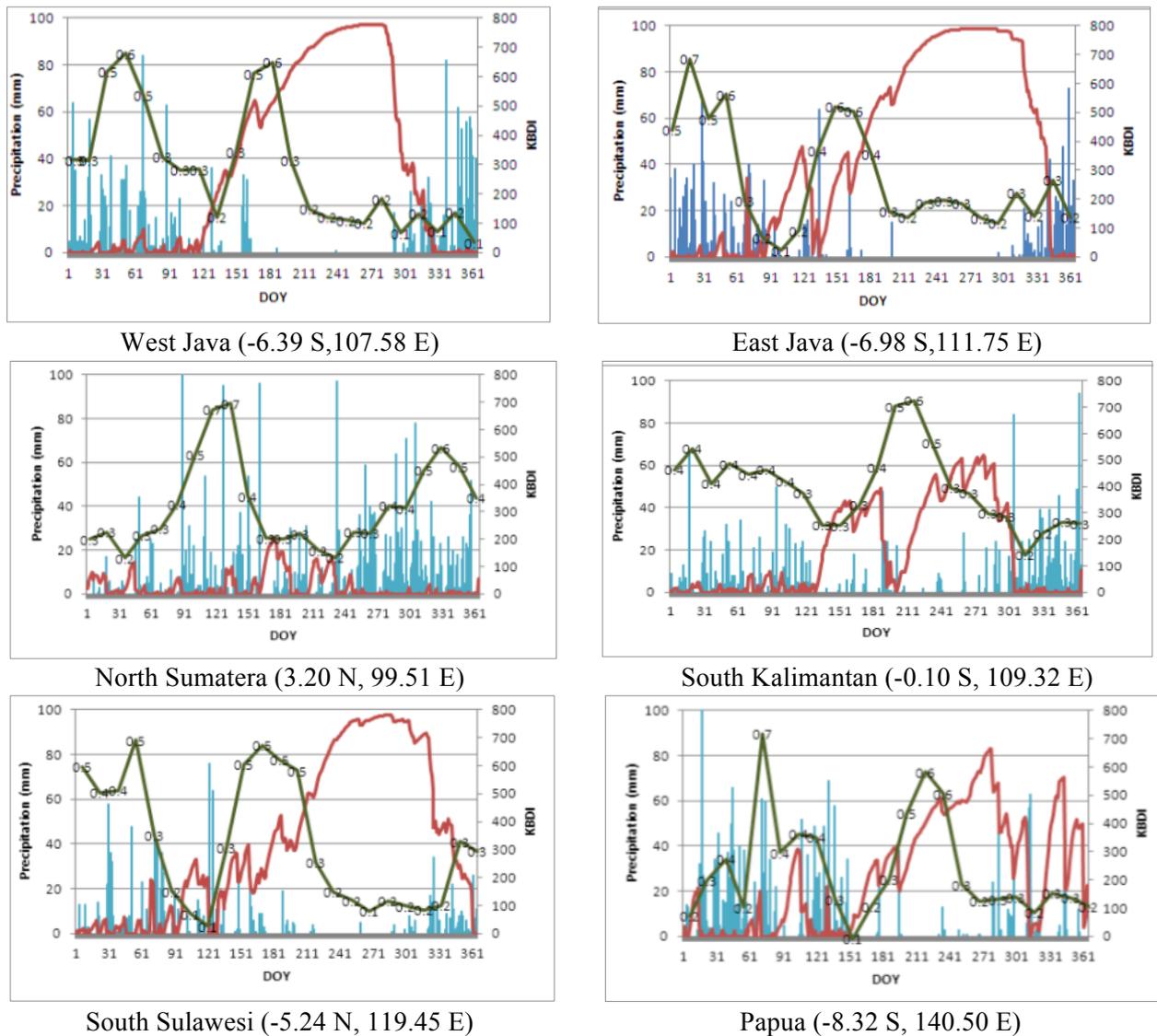


Figure 4. Seasonal variability of EVI, Precipitation and KBDI in 2012
 EVI (green line), precipitation (blue line) and KBDI (red line).

In West Java and East Java precipitation begins from January until May and October until December and from KBDI begins to increase from June and peak in September. In North Sumatera and South Kalimantan precipitation almost occurs all the month so KBDI value not height. In South Sulawesi precipitation begins from January until February and November until December so KBDI begins to increase from March and peak in October. In Papua precipitation begins from January until June and September until December so KBDI begins to increase from July and peak in the August. Seasonal variability of precipitation and KBDI is different for each province. According to Aldrian and Susanto [19], in Indonesia seasonal variability of precipitation is categorized on three regions, that is region A

(West Java, East Java, South Kalimantan, South Sulawesi and Papua) has one peak and one valley rainfall and is influenced by two monsoon systems, the northwest monsoon (wet seasons) from November to March, and the southeast monsoon (dry seasons) from May to September. Region B (North Sumatera) has two peaks of rainfall in October–November and March–May. Those two peaks are associated with the southward and northward movement of the inter-tropical convergence zone. Region C has one peak and one valley rainfall, namely June–July for the wet season and November–February for the dry season.

We have calculated also EVI, precipitation and KBDI from 2007 until 2012, can see on figure 4. Mostly seasonal variability of EVI influenced by precipitation and KBDI. Peak of EVI occurs before peak of KBDI occurs and increasing of KBDI followed by decreasing of EVI.

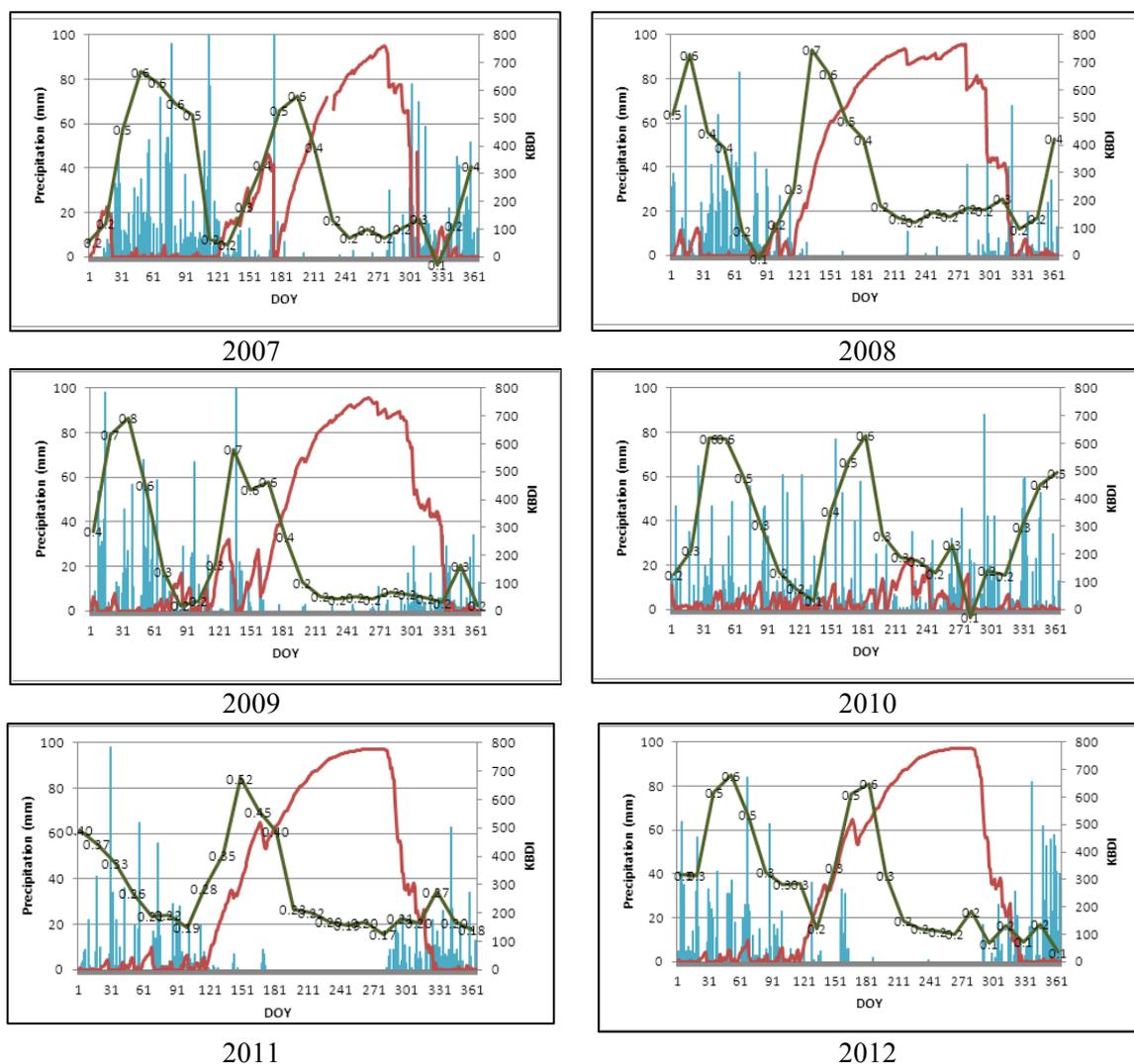


Figure 5. Seasonal variability of precipitation, KBDI and EVI 2007 – 2012 in West Java
EVI (green line), precipitation (blue line) and KBDI (red line).

Basically In 2010, for all province got higher precipitation and smaller KBDI so that EVI has three

peaks such as in West Java (Figure 4.) that can increase rice production. According to [20], paddy field production in Indonesia is subject to considerable climate variability that is mostly attributable to the El Niño-Southern Oscillation (ENSO) phenomenon.

4. Conclusion

We have showed seasonal variability of precipitation, KBDI and EVI. Precipitation begins from January until May and October until December, and KBDI begins to increase from June and peak in September only in South Sumatera precipitation almost in all month. Seasonal variability has showed precipitation and KBDI affect on EVI that can indicate variety phenology of Indonesia paddy field. Peak of EVI occurs before peak of KBDI occurs and increasing of KBDI followed by decreasing of EVI. In 2010 all province got higher precipitation and smaller KBDI so EVI has three peaks such as in West Java that can increase rice production. For future works, we will predict precipitation and drought and estimate rice production in study area.

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