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# Indonesian drought monitoring from space. A report of SAFE activity: Assessment of drought impact on rice production in Indonesia by satellite remote sensing and dissemination with web-GIS

# Rizatus Shofiyati<sup>1\*</sup>, Wataru Takeuchi<sup>2</sup>, Parwati Sofan<sup>3</sup>,Soni Darmawan<sup>4</sup>, Awaluddin<sup>5</sup>, andWahyu Supriatna<sup>1</sup>

<sup>1.</sup>Indonesian Center for Agricultural Land Resources Research and Development (ICALRD)

<sup>2.</sup> University of Tokyo, Japan

<sup>3</sup> Indonesian National Institute of Aeronautics and Space (LAPAN)

<sup>4</sup> Bandung Institute of Technology (ITB), Indonesia

<sup>5</sup>Agency for the Assessment and Application of Technology (BPPT), Indonesia

\*Corresponding author: rshofiyati@litbang.deptan.go.id or rshofiyati@yahoo.com Jalan Tentara Pelajar 12, Cimanggu, Bogor, Indonesia

Abstract. Long droughts experienced in Indonesia in the past are identified as one of the main factors in the failure of rice production. In this regard, special attention to monitor the condition is encouraged to reduce the damage. Currently, various satellite data and approaches can withdraw valuable information for monitoring and anticipating drought hazards. Two types of drought, Meteorology and Agriculture, have been assessed. During the last 10 years, daily and monthly rainfall data derived from TRMM and GSMaP. MTSAT and AMSR-E data have been analyzed to identify meteorological drought. Agricultural drought has been studied by observing the character of some indices (EVI, VCI, VHI, LST, and NDVI) of sixteen-day and monthly MODIS data at a period of 5 years (2009 - 2013). Network for data transfer has been built between LAPAN (data provider), ICALRD (implementer), IAARD Cloud Computing, and University of Tokyo (technical supporter). A Web-GIS based Drought Monitoring Information System has been developed to disseminate the information to end users. This paper describes the implementation of remote sensing drought monitoring model and development of Web-GIS and satellite based information system.

#### 1. Introduction

In Indonesia, the drought has occurred more frequently in recent years. Drought usually disrupts rice production. Sufficient data and information must be very important to anticipate this situation and would be strategic for agricultural development policy decision. Agricultural monitoring techniques to determine land surface information in near real time is needed and further analysis of data can be used in the current agricultural development planning.

Remote sensing has an ability to provide spatial information which can cover wide area and record multi - temporal information to help anticipate drought condition. Remote sensing has proven useful for large-area vegetation monitoring given the synoptic coverage, high temporal repeat cycle,

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continuity, and moderate resolution observation of satellite-based sensors. In particular, normalized difference vegetation index (NDVI) time-series data from the global imager, the Moderate Resolution Imaging Spectroradiometer (MODIS) and National Oceanic and Atmospheric Administration -Advanced Very-High-Resolution Radiometer (NOAA - AVHRR), have been widely used for vegetation and ecosystem monitoring [1,2,3]. Analysis of NDVI time-series data and NDVI-derived metrics have been an effective means in identifying vegetation condition anomalies (e.g., apparent declines in vegetation health). Operational efforts such as the U.S. Drought Monitor [4], National Drought Mitigation Center [5], and NOAA's National Weather Service [6] provide NDVI-derived products that describe the percentage or deviation of current vegetation conditions from the normal conditions are expressed historically in the NDVI data. The vegetation condition index (VCI) [7], which is based on a transformational of the AVHRR NDVI data, and the temperature condition index (TCI) calculated from AVHRR's thermal data [8] are operationally produced and commonly used for national- to global-scale drought monitoring [9,10,11]. Although these numerous operational products have been useful for vegetation monitoring, they are limited for effectively characterizing the impact of drought on vegetation because the anomalies caused by drought stress cannot be discriminated from anomalies produced by other environmental causes of vegetation stress (e.g., flooding, fire, pest infestation, and hail damage) and anthropogenic drivers (e.g., land cover/land use conversion). Additional information is required to discriminate the drought-impacted areas from locations where the vegetation is being influenced by these other environmental and anthropogenic factors [12].

Traditionally, climate-based drought indicators such as the palmer drought severity index (PDSI) and standardized precipitation index (SPI) have been used for drought monitoring. However, climate-based drought monitoring approaches have limited spatial precision at which drought patterns can be mapped since the indices are calculated from point-based meteorological measurements collected at weather station locations [13, 14]. In addition, weather stations are scarce in remote areas and they are not uniformly distributed. As a result, climate-based drought index maps depict broad-scale drought patterns that are produced from point-based data using statistical-based spatial interpolation techniques and the level of spatial detail in those patterns is highly dependent on the density and distribution of weather stations. Therefore, the spatial detail in climate-based drought index maps is limited due to the dependence on uneven and sparse weather station distributions, which limits drought planning and monitoring activities in areas not well covered by weather stations [12].

Several methods have been studied to identify drought level, such as standardized precipitation index (SPI) [15] and keetch-byram drought index (KBDI) for meteorological drought, normalized difference vegetation index (NDVI) anomalies, enhanced vegetation index (EVI) anomalies, vegetation condition index (VCI), temperature condition index (TCI), and vegetation health index (VHI). Satellite data used are MODIS, MTSAT, AMSR-E. Analysis shows that these methods can be used to identify the presence of anomalous levels of dryness and drought in the central region of rice.

This study is aimed to assess the use of satellite data to monitor drought conditions in paddy field in near real time, validate satellite -based drought models with field observation data, and disseminate the results by developing a Web-GIS satellite based system that is integrated with an existing crop calendar information system. The results of this study can be used to determine spatial location of drought area and its effect on rice production. Results are expected to help provide recommendations to prevent future agricultural drought events.

# 2. Methodology and data used

Human factors, such as water demand and water management can exacerbate the impact that drought has on a region. Because of the interplay between a natural drought event and various human factors, drought means different things to different people. In practice, drought is defined in a number of ways that reflect various perspectives and interests [16]. Wilhite and Glantz [17] categorized the definitions in terms of four basic approaches to measuring drought, namely meteorological, hydrological, agricultural, and socioeconomic. The first three approaches are dealt with ways to measure drought as

a physical phenomenon. The last is dealing with drought in terms of supply and demand, tracking the effects of water shortfall as it ripples through socioeconomic systems.

Drought types having been analyzed for this study are meteorological and agriculture drought that are based on research conducted by Takeuchi and Gonzalez [8] and Roswintiati *et al.* [18, 19]. Several methods of meteorological drought index have been utilized. KBDI and the SPI of the daily and monthly rainfall data from TRMM and GSMap have been analyzed for several research areas in the last seven years. A 5-year time series (2009 – 2005) of 16-days composited of 250-m Terra MODIS data was used to process and analyze agricultural drought by observing some characters of some indices. The data used and performance analysis are presented in Table 1.

Satellite data	Description	Analysis	Data provider
MODIS	Resolution 250 m (16-day composite)	TCI, VCI, VHI	LAPAN
MTSAT	Resolution 4 km (daily)	KBDI	Univ of Tokyo
GSMaps	Resolution 0.1 deg (every hour)	Daily rainfall data	Univ of Tokyo

**Table 1.** Satellite data used and analyzed.

Classification of Kogan [7, 20] has been used to classify agricultural drought which has 5 classes (Table 2). The classification system is simpler than a more difficult to identify in the field of the 9th class of NEDIS NOAA.

Table 2. Drought classification.			
SPI	Description		
VHI > 40	No drought		
$30 > VHI \geq 40$	Mild drought		
$20 > VHI \geq 30$	Moderate drought		
$10 > VHI \geq 20$	Severe drought		
$VHI \leq 10$	Extreme drought		

 Table 2. Drought classification.

The following Figure 1 shows the flowchart of the study by integrating existing model using ground rainfall data and satellite data to obtain drought information. The information could facilitate farmers to plan their planting time, and local government to determine regional planning development, especially in agricultural field.



A number of institutions are involved in this project. The prototyping executor is the Indonesian Center for Agricultural Land Resources Research and Development (ICALRD) of Indonesian Agency for Agricultural Research and Development (IAARD), Ministry of Agriculture (MoA). Technical support is provided by the University of Tokyo, Geoinformatics Center (GIC) of the Asian Institute of Technology (AIT), Indonesian National Institute of Aeronautics and Space (LAPAN), and the Agency for the Assessment and Application of Technology (BPPT). JAXA provides MODIS, MTSAT, AMSR-E and ALOS data, the University of Tokyo supports the meteorological drought index, LAPAN provides agricultural drought index, BPPT develops Web-based Information System, and ICALRD-IAARD provides crop calendar data and rainfall data. End users are Indonesian local government services and farmers through extension officers. The results will be introduced and disseminated through workshops and seminars as well as through a web portal.

# 3. Results and discussions

Several methods have been studied to identify the index of drought in Indonesia, such as keetch-byram drought index (KBDI) for meteorological drought, normalized difference vegetation index (NDVI) anomaly, enhanced vegetation index (EVI) anomaly, vegetation condition index (VCI), temperature condition index (TCI), and vegetation health index (VHI). It reveals that these methods can be used to identify the level and anomaly of drought in rice production centers. The results of analysis shows that rainfall data derived from GSMap, KBDI of AMSR-E, and LSWC of MTSAT can be used to identify the level of meteorological drought. While NDVI, VCI, TCI, VHI from satellite data Terra MODIS resolution of 250 mx 250 m have been analyzed to identify agricultural drought level.

# 3.1. Drought analysis

Results at the district level show that MODIS data of 250 mx 250 m resolution can be applied and produce sufficient information to indicate drought conditions through the analysis of VCI, TCI and VHI. Terra MODIS resolution of 250 mx 250 m in the district of Indramayu is presented in Figure 2. The spatial resolution is sufficient to figure out detail information drought conditions at such district level. Based on the rainfall data obtained from satellite data GSMap, in 2009, the lowest amount of rainfall occurs during July to November, and the analysis indicates drought anomalies of KBDI. Different conditions occur in 2010, rainfall data and KBDI analysis shows that the region is not experiencing drought.



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IOP Conf. Series: Earth and Environmental Science 20 (2014) 012048	doi:10.1088/1755-1315/20/1/012048

VHI characterizes vegetation health by combining estimation of moisture (VCI) and thermal (TCI) conditions [21]. KBDI measures the amount of moisture in the top layer of soil and covering leaves and vegetation [22]. The KBDI considers drought as an index on a scale from 0 to 2000, based on the moisture content of the soil [23]. It measures the amount of moisture in the top layer of soil and covers leaves and vegetation. Typical drought anomalies can be indicated by the increasing value of KBDI, as well as the decline value of VHI.

NDVI estimates photosynthetically absorbtion of radiation over the land surfaces [24, 25], at which it can gives a measure of the vegetative cover and displays greenness level on the land surface [26]. NDVI can show a number of paddy planting seasons, namely (a) at study location of Ngawi District, East Java Province indicates that the area has three planting time of paddy, and (b) at study location of Indramayu District, West Java Province which has two planting seasons. NDVI value indicates that the decrease is not directly affected by declining of precipitation.

Pattern of KBDI,VHI, NDVI, and TCI to precipitation are presented in Figure 3. KBDI can indicate drought anomaly. A small amount of rainfall shows an increase in KBDI that can be used as a meteorological drought parameters. However, in both study sites, drought anomalies indicated by KBDI does not necessarily affect the condition of vegetation. This means that the level of drought is not causing damage to rice crop. The VHI pattern is more sensitive to vegetation condition. At both locations, the decreasing of VHI value, which indicates drought, is followed by the decrease in the value of NDVI or greenness of vegetation. Similarly, on the opposite condition, the drought classification of VHI can be used to identify agricultural drought. In this respect, there is no correlation between KBDI and VHI and the increasing value of KBDI has no effect on VHI value.

# 3.2. Result Verification

Field verification was conducted during the dry season of August-September 2013 in Indramayu (Figure 4), West Java; DI Yogyakarta; Barito Kuala, South Kalimantan; Ngawi and Pasuruan, East Java, and Maros, South Sulawesi. The results show that the value of 500-600 KBDI obtained from MTSAT data indicates beginning of meteorological drought in paddy field. While agricultural drought, through VHI analysis of MODIS, has 60 % accuracy.



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IOP Conf. Series: Earth and Environmental Science <b>20</b> (2014) 012048	doi:10.1088/1755-1315/20/1/012048

In addition to field verification, several workshops and coordination meetings, such as Focus Group Discussion (FGD) and Workshops are conducted to enhance the output and to get feedback from end users. These meetings were attended by policy makers and other stakeholders such as farmers' coordinators, regional institutions' representatives, extension agents, and researchers.

# 3.3. Dissemination with Web-GIS

The result of the analysis of the level of agricultural drought is presented in printed form of drought levels distribution map of paddy fields as shown in Figure 5. This is also presented in Web-GIS based information system that can be accessed via internet for wider community. The Web-GIS based information system provides information on interactive and integrated drought condition by using Google API.



The Indonesian Information System for Drought Monitoring is a daily and monthly product that provides a general summary of current meteorological and agricultural drought conditions. Multiple drought indicators, including various indices, outlooks, field reports, and news accounts are reviewed and synthesized. In addition, numerous experts from agencies and offices across the country are consulted and involved to generate the product. The result is the consensus assessment presented on the drought level map. Agricultural drought monitoring is presented in Indonesian Information System for Drought Monitoring as shown in Figure 6. Meterological drought monitoring and information can be searched at webgms.iis.u-tokyo.ac.jp [27] as shown in Figure 7.

doi:10.1088/1755-1315/20/1/012048



Figure 6. Web-GIS based information system of drought monitoring.



Figure 7. Meteorological drought monitoring information system.

# 4. Conclusions

In respect to the assessment of drought impact on rice production, several findings could be drawn from this study. These are related to the development models to create Web-GIS and satellite based information system.

The study reveals that the data obtained from NDVI and VHI from Terra MODIS resolution of 250 mx 250 m, rainfall data from GSMap, and KBDI from AMSR – E can be used to identify the presence of anomalous levels of dryness and drought in rice producing centers. Meanwhile, NDVI, VHI, KBDI

can represent rainfall anomalies and also capture the onset of drought. VHI from MODIS, KBDI of MTSAT can be also be used to identify patterns of plant with its index to estimate the results.

Validation having been carried out in Indramayu district of West Java Province; Barito Kuala district of South Kalimantan Province, Ngawi and Pasuruan districts of East JavaProvince, and Yogyakarta of DI Yogyakarta Province indicate that (a) Meteorological drought for KBDI analysis with value ranging from 500 to 600 show the beginning of drought in paddy field, and (b) agricultural drought by analyzing VHI of 250 m x 250 m Terra MODIS has shown quite confident of 60 % accuracy.

Interactive and integrated Web-GIS based system using the Google API has been developed to disseminate information of drought condition for wider community. This is very important in preparing remote sensing based data for decision making process in the national agricultural development policies.

#### Acknowledgment

The authors are grateful to the Indonesian Center of Agricultural Land Resources Research and Development (ICALRD) of the Indonesian Agency of Agricultural Research and Development (IAARD), Ministry of Agriculture for opportunity to work on this study and to provide facilities, data, and encouragement to complete this study. Thanks are also conveyed to Japan Aerospace Exploration Agency (JAXA), Japan for providing satellite data and transfer of technology during the project activities. Many thanks are also delivered to University of Tokyo and to the Agency for Assessment and Application of Technology (BPPT) for providing technical support and facilities to develop Crop Monitoring System Information. Our thankful are also extended the Indonesian National Institute of Aeronautics and Space (LAPAN) for facilitating this collaboration.

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