COMPARATIVE ASSESSMENT OF NDVI VERSUS NDDI TO INDICATE AGRICULTURAL DROUGHT

A CASE STUDY CARRIED OUT IN DISTRICT OF GUNUNGKIDUL, PROVINCE OF YOGYAKARTA SPECIAL REGION

Thesis

Presented as partial fulfillment for the requirement
to obtain a Master Degree of Science
in Geo-Information for Spatial Planning and Risk Management

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DOUBLE DEGREE M.Sc. PROGRAMME
THE GRADUATE SCHOOL OF UNIVERSITAS GADJAH MADA
INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH OBSERVATION
2015

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was defended before the Board of Examiner in Yogyakarta

On May , 2015

By Thesis Proposal Assessment Board:

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Examiner 1	Examiner 2
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This thesis has been accepted as one of the requirements to obtain a Master Degree

Date …………………………………………………….

Program director of Geo-Information for Spatial Planning and Disaster Risk Management, Graduate School Gadjah ada University	On behalf of Director, Vice Director for Academic Affairs, Development, and Cooperation Graduate School Gadjah ada University
Prof. Dr. H. A. Sudibyakto M.S.	______________________________

Disclaimer
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Yogyakarta, May 2015
Author

Astisiasari

ABSTRACT

The research compared the satellite-based indices, the NDVI and the NDDI, to identify agricultural drought in the District of Gunungkidul, Province of Yogyakarta Special Region. It compared the performance of those two derived indices from MOD09A1 hyper-temporal images, to prove which one performs better as an agricultural drought indicator.

The assessment of agricultural drought in the District of Gunungkidul, Province of Yogyakarta Special Region, does not exist yet. To this regard, the study may help to get a better understanding on the agricultural drought pattern, as well as to bring benefit knowledge for drought management and mitigation. Besides, it would be bridging the gap from the previous studies that did not correlate the NDDI to the impacts of drought, while proofing the NDDI's better performance statement as drought indices. The best proof is by evaluating indices with the factual past achieved agricultural-productivity data. Therefore, this study intended to broaden the research base that promotes and supports the use of NDDI as a drought indicator.

The research had the pixel-based analysis to identify the anomaly of two indices, from examining the profile parameters of seasonal graph, i.e.: (1) start-end period of the paddy growing season; (2) day length of the paddy growing season; (3) mean values of indices during a paddy growing season; (4) values of minimum, maximum, and amplitude; and (5) the grow-up rate. Then, compared the anomalies with the paddy productivity, using correlation statistic.

District of Gunungkidul was found not to experience a severe agricultural drought. However, several anomalies of vegetation greenness performance were found in 2003 – 2005, 2007, 2009, and 2011 – 2012. This deviated condition was corresponded to the decreasing productivity in the exact same years. Some area that experienced poor vegetation performance in anomaly periods was in Sub-districts of Paliyan, Wonosari, and Panggang. These sub-districts commonly experienced the performance of photosynthetic activity from paddy greenness that was lower than the NDVI normal condition, and higher than the NDDI normal condition. However, generally all sub-districts experienced a slight decline from the indices' normal behavior over years.

The NDDI was found outperform the NDVI in correlation with the rain-fed paddy productivity. The NDDI to paddy productivity correlation in terms of indices' mean values was 38.19 %; normal behavior was 82.60 %; and standardized (z-score) anomaly value was 0.2628. While NDVI to paddy productivity has correlated 32.51 % in indices' mean values, -68.55 % in normal behavior, and -0.51 in standardized (z-score) anomaly values. Taking everything into consideration, NDDI could be suggested as a better index to indicate the agricultural drought, corresponded to its stronger relation with the crop productivity.

Keywords: NDVI, NDDI, MOD09A1, agricultural, drought, Gunungkidul

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LIST OF ABBREVIATIONS

BAPPEDA	: Agency of Regional Development Planning
BIG	: Geospatial Information Agency
BMKG	: Agency for Meteorology, Climatology & Geophysics
BPS	: Central Bureau of Statistics
CGS	: Crop Growing Season
DAT	: Days After Transplanting
DOY	: Day of Year
FAO	: Food and Agricultural Organization
GRDP	: Gross Regional Domestic Product
ISODATA	: Iterative Self-Organizing Data Analysis Technique Algorithm
LAPAN	: National Institute of Aeronautics and Space
LOC	: Length of Cycle
LP DAAC	: Land Processes Distributed Active Archive Center
MOD09A1	: 8-days MODIS Terra Image at 500-meter of spatial resolution
MODIS	: Moderate Resolution Imaging Spectroradiometer
NDVI	: Normalized Difference Vegetation Index
NDDI	: Normalized Difference Drought Index
NDWI	: Normalized Difference Water Index
NIR	: Near Infrared
Puslitanak (PPT)	: Soil and Agro-climate Research Center
SRTM	: Shuttle Radar Topography Mission
SWIR	: Shortwave Infrared
WMO	: World Meteorological Organization

1. INTRODUCTION

1.1 Background

1.1.1 Drought and Agricultural Productivity in District of Gunungkidul, Province of Yogyakarta Special Region, Indonesia

Drought is a condition of water supply deficiency over an extended period that makes it drier than normal (Moreland, 2001; NOAA, 2008). It is a deviated condition from a normal circumstance that can lead to problems related to water. Therefore to detect the drought, it requires the negative anomaly analysis from its normal behavior.

Generally, drought hazard has several terms based on its perspectives, e.g., meteorological drought, hydrological drought, and agricultural drought (NOAA, 2008; Rougier, Sparks, & Hill, 2013). Particularly, each types of drought deal with the natural condition over a certain area, e.g., precipitation, temperature, evapotranspiration, water reserve, soil moisture, vegetation greenness, etc. (Mokhtari, 2005).

Agricultural drought is expressed as the affect on crops from the deficiency of available soil moisture as adequate water retained in the root zone. Water infiltration into soil that affects the soil moisture is not directly correlated to the rainfall. Yet, soil water holding capacity is variedly influenced by soil type, slope, rainfall intensity, as well as evapotranspiration (World Meteorological Organization, 2006).

Related to the disaster, agricultural drought has potential threats to cause a severe effect to crop production as well as to agricultural system (Nagarajan, 2010). In some parts of Indonesia, drought has been a challenging problem. One of drought cases happens yearly in the District of Gunungkidul, Province of Yogyakarta Special Region (see Figure 1-1 for the study area), especially in the karsts area on the Southern part as well as in the hilly area on the Northern part (Fathoni & Priadmodjo, 2013).

Regarding the drought disaster, mass media had reported the effects of drought in District of Gunungkidul, Province of Yogyakarta Special Region. In 2011, fifteen (15) sub-districts out of eighteen (18) sub-districts there experienced a wide spreading drought (from ten sub-districts in 2010). In 2011, drought disaster had caused thousands of residents in 171 hamlets needed a clean water supply, where sub-district of Ngawen and Panggang had experienced the worst drought. (http://news.okezone.com/, http://krjogja.com/, http://www.data1.sapa.or.id/).

In fact, agriculture sector plays a significant contribution to the Gross Regional Domestic Product (GRDP) of Gunungkidul District (BPS, 2013b), where in 2013, Agriculture sector supported 36.49 % (Rp. 1,329,212 Million) that contributes as the highest above other sectors. Here, agricultural crops covers of many cultivated plants of food crops (cereals, vegetables, fruits) and specialty crops (cotton, tobacco, herbs, etc.). In District of Gunungkidul, Province of Yogyakarta Special Region, agricultural commodities yields are produced from paddy field (wet-land and dry-land paddy) and dry land (maize, cassava, sweet potatoes, peanuts, and beans). Yet mainly, the agricultural productivity in this research will be focused on rain-fed paddy crop.

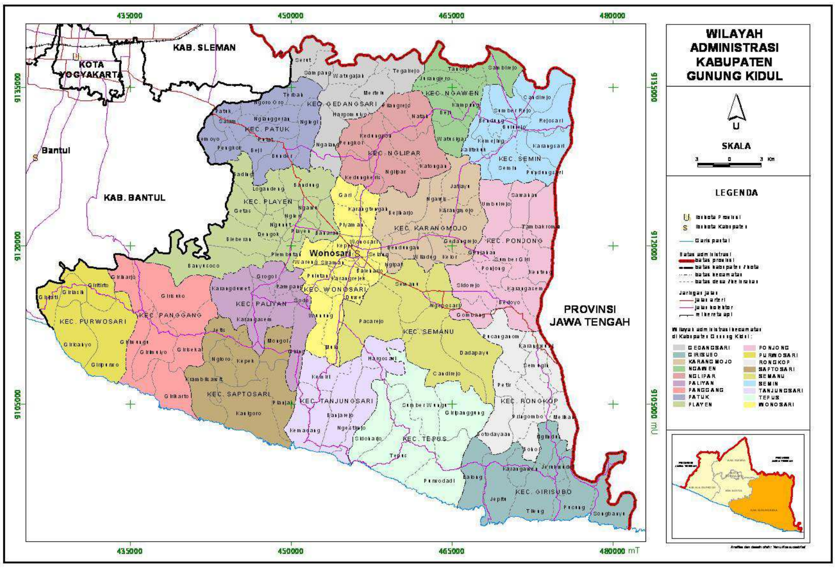

Figure 1-1 Administration Map of Gunungkidul District: The Area of Study
Source: (Regional Planning Board of Gunungkidul, 2006)

In the District of Gunungkidul, Province of Yogyakarta Special Region, drought has become an important issue for farmers and local government. Unfortunately, monitoring of agricultural drought in this area does not exist yet. To this regard, the study will help to get a better understanding on the agricultural drought pattern, as well as to bring benefit knowledge for agricultural drought management and mitigation (de Bie, 2014; personal communication).

1.1.2 Indices to Assess Drought

Satellite-based indices are able to indicate the complexity of the geo-meteorological environment, where in this sense is to monitor and identify drought. To this regard, a drought index that can possibly be used is the Normalized Difference Drought Index (NDDI). It is a relatively new index, developed in 2007 by Gu et all. Until now, very few studies are carried out to assess the use of NDDI.

The research by Gu et all. (2007) assessed NDDI derived from hyper-temporal MODIS imageries for grasslands. NDDI was found to have more vigorous response to drought than the use of solely NDVI (The Normalized Difference Vegetation Index) or NDWI (The Normalized Difference Water Index) (Gu, Brown, Verdin, & Wardlow, 2007). Another NDDI research was conducted by Renza et all. (2010) on different vegetation types using Landsat imagery, where NDDI also indicated a stronger response to drought than the use of NDVI and NDWI (Renza, Martinez, Arquero, & Sanchez, 2010). As a comparison, the values of NDVI and NDWI are strongly correlated to the vegetation greenness, while NDDI indicates the dryness period over an area. Therefore, a lower values of NDVI and NDWI will increase the values of NDDI (see figure 1-2) (Mongkolsawat, Wattanakij, & Kamchai, 2009).

NDDI combines the parameters of vegetation greenness (NDVI) and vegetation water-content (NDWI). In NDDI, a higher value indicates a drier condition. The formula for NDDI is (Gu et al., 2008):

$$NDDI = \frac{(NDVI - NDWI)}{(NDVI + NDWI)}$$

The Normalized Difference Vegetation Index (NDVI) expresses the photosynthetic active vegetation greenness. It can be used to detect extreme periods when agricultural crops are affected by moisture deficit (Gu et al., 2007; Ryu et al., 2011). NDVI uses the reflectance values from the red band and the Near Infrared (NIR) band. The formula for NDVI is:

$$NDVI = \frac{(NIR\ band - Red\ band)}{(NIR\ band + Red\ band)}$$

The Normalized Difference Water Index (NDWI) expresses the water content of vegetation (Gu et al., 2007; Ryu et al., 2011). NDWI uses the reflectance values from the Near Infrared (NIR) band and the Shortwave Infrared (SWIR) band. The formula for NDWI is:

$$NDWI = \frac{(NIR\ band - \mathrm{SWIR}\ band)}{(NIR\ band + \mathrm{SWIR}\ band)}$$

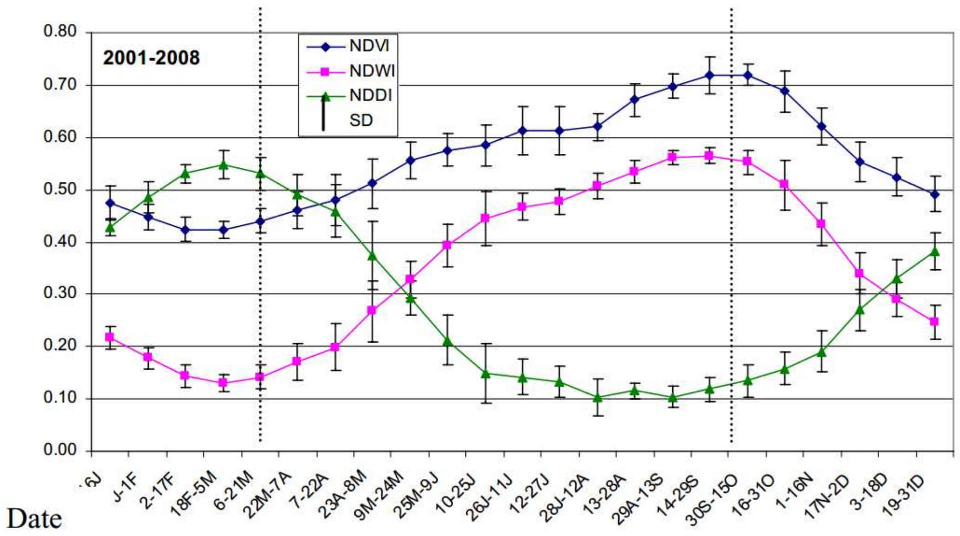

Figure 1-2 Relationships between 8 years-mean satellite-derived indices (NDVI, NDWI, and NDDI) from Modis Terra 16-days, 250 meter
Source: Mongkolsawat, Wattanakij, & Kamchai, 2009

A challenge to assess drought in District of Gunungkidul, Province of Yogyakarta Special Region is to evaluate if NDDI indeed performs as a better index than the NDVI, commonly used for crop monitoring. Moreover, this study intends to broaden the research base that promotes and supports the use of NDDI as a drought indicator (de Bie, 2014; personal communication).

Formerly, the research by Gu et al., (2007) and Renza et al., (2010) did not correlate NDDI to the impacts of drought on e.g. biomass or productivity. To this regard, the best proof if the NDDI outperforms the NDVI is by evaluating which one correlates better to the caused impacts. Related to the area of study in District of Gunungkidul, Province of Yogyakarta Special Region, this study intends to compare the performance of the two drought indices (NDDI and NDVI), when related to the factual past achieved agricultural-productivity data.

1.2 Problem Statement

The assessment of agricultural drought in the District of Gunungkidul, Province of Yogyakarta Special Region, does not exist yet. To this regard, the study will help to get a better understanding on the agricultural drought pattern, as well as to bring benefit knowledge for drought management and mitigation.

There is a challenge to evaluate if NDDI performs as a better index than the NDVI, commonly used for crop monitoring. The best proof is by evaluating which one correlates better to the caused impacts; that is the factual past achieved agricultural-productivity data. Moreover, this study intends to broaden the research base that promotes and supports the use of NDDI as a drought indicator.

1.3 Objective and Research Questions

1.3.1 Research Objective

The general objective of this research is to assess if the use of NDDI outperforms NDVI to indicate the impact of agricultural drought.

1.3.2 Research Questions

Based on the research objective and problem statement, specific objectives of this research are generated into some research questions as:

Table 1-1. Specific Objectives and Research Questions

SPECIFIC OBJECTIVES	RESEARCH QUESTIONS
To quantify two drought indicators (NDVI and NDDI) in District of Gunungkidul, Province of Yogyakarta Special Region. To identify the paddy field locations	1. When during a crop growing season did the drought happen? 2. Based on NDVI and NDDI negative anomaly interpretation, where are the paddy field locations that may have experienced drought?
To relate the drought indicators (NDVI and NDDI) to the agricultural productivity in District of Gunungkidul, Province of Yogyakarta Special Region.	4. How strong are the correlations of the derived drought indicators values with the paddy crop productivity? 5. Which one of the two drought indicators performs best to indicate the agricultural drought?

1.4 Methodological Flowchart

1.4.1 Conceptual Framework

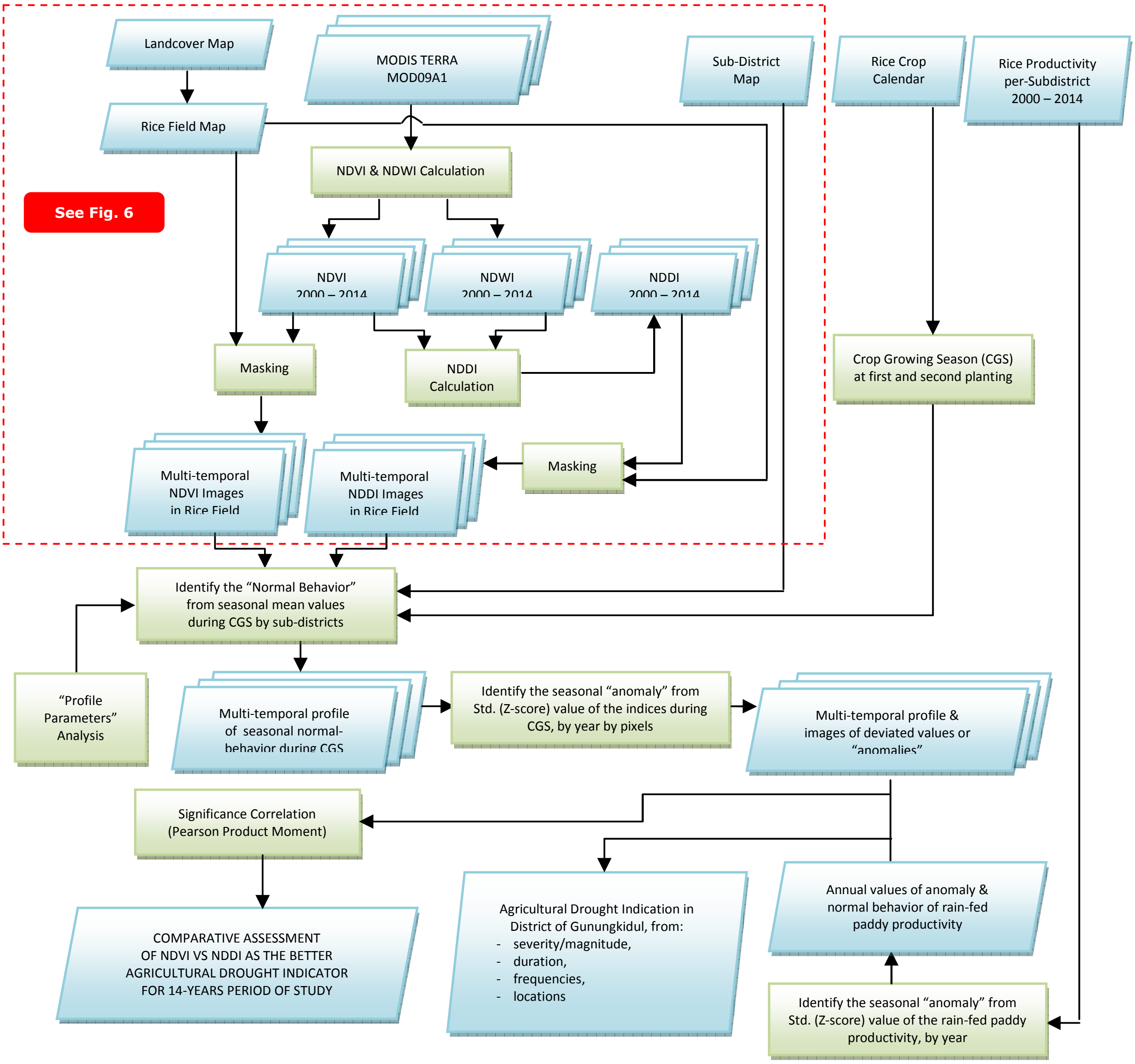

Figure 1-3 Conceptual Framework

1.4.2 Methodological Framework

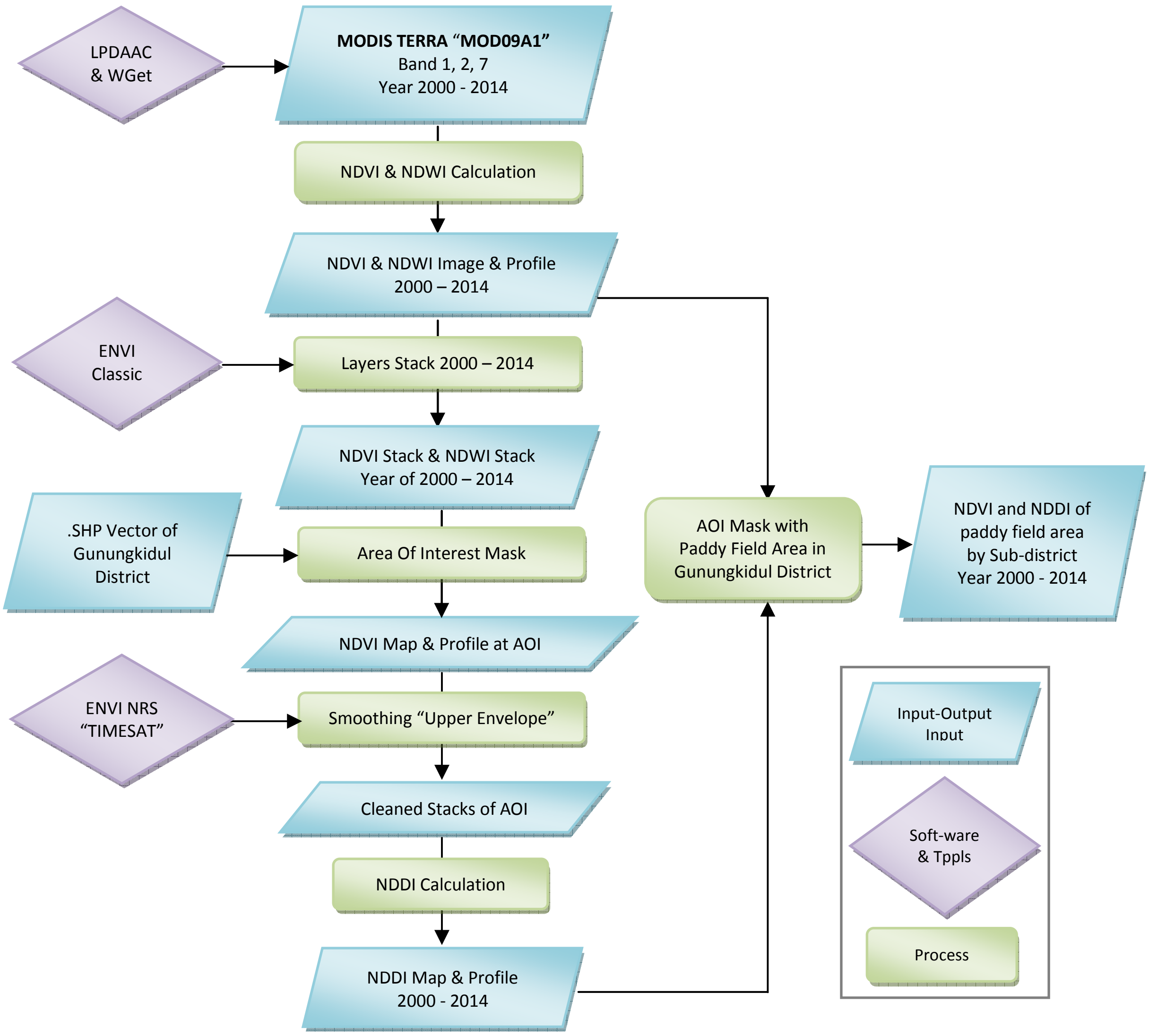

Figure 1-4 Methodological Framework

2. LITERATURE REVIEW

2.1 Agricultural Drought and Its Occurrence in District of Gunungkidul

Drought is a condition of water supply deficiency over an extended period that makes it drier than normal (Moreland, 2001; NOAA, 2008). It is a deviated condition from a normal circumstance that can lead to problems related to water. Therefore to detect the drought, it requires the negative anomaly analysis from its normal behavior.

Generally, drought hazard has several terms based on its perspectives, e.g., meteorological drought, hydrological drought, and agricultural drought (NOAA, 2008; Rougier et al., 2013) as seen in Figure 2-1 below. Particularly, each types of drought deal with the natural condition over a certain area, e.g., precipitation, temperature, evapotranspiration, water reserve, soil moisture, vegetation greenness, etc. (Mokhtari, 2005).

Agricultural drought is expressed as the affect on crops from the deficiency of available soil moisture as adequate water retained in the root zone. Water infiltration into soil that affects the soil moisture is not directly correlated to the rainfall. Yet, soil water holding capacity is variedly influenced by soil type, slope, rainfall intensity, as well as evapotranspiration (World Meteorological Organization, 2006).

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Regarding the drought disaster, mass media had reported the effects of drought in District of Gunungkidul, Province of Yogyakarta Special Region. In 2011, fifteen (15) sub-districts out of eighteen (18) sub-districts there experienced a wide spreading drought (from ten sub-districts in 2010). In 2011, drought disaster had caused thousands of residents in 171 hamlets needed a clean water supply, where sub-district of Ngawen and Panggang had experienced the worst drought. (http://news.okezone.com/, http://krjogja.com/, http://www.data1.sapa.or.id/).

In the District of Gunungkidul, Province of Yogyakarta Special Region, drought has become an important issue for farmers and local government. Unfortunately, monitoring of agricultural drought in this area does not exist yet. To this regard, the study will help to get a better understanding on the agricultural drought pattern, as well as to bring benefit knowledge for drought management and mitigation.

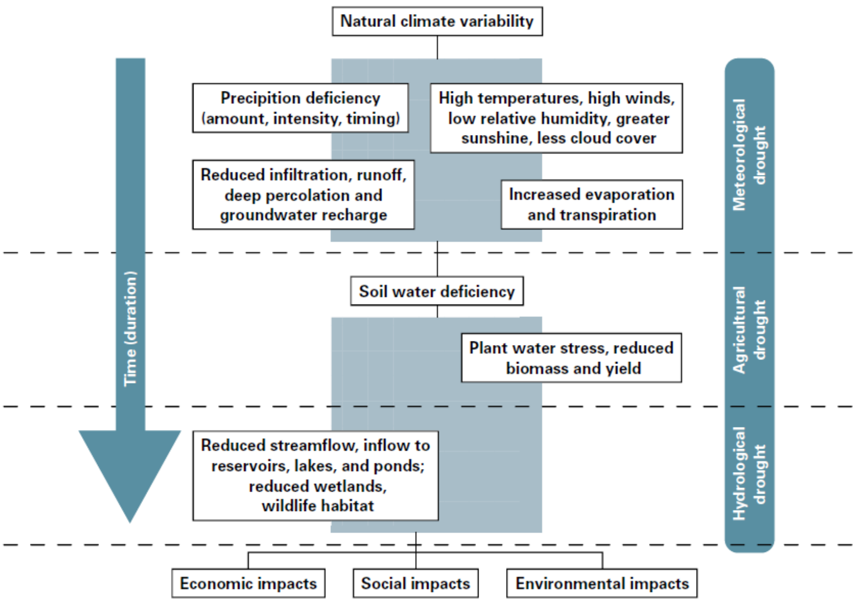


Figure 2-1 Sequence of drought occurrence & commonly accepted drought types
Source: (World Meteorological Organization, 2006)

2.2 Satellite Image of MODIS TERRA “MOD09A1” for Drought Indication

Satellite-based indices are able to indicate the complexity of the geo-meteorological environment; where in this sense is related to the monitoring and identifying drought. The agro-ecosystems show a higher seasonal variability compared to its spatial dynamic (C. a. J. M. De Bie, Khan, Toxopeus, Venus, &

Skidmore, 2008). To this regard, a set of hyper-temporal satellite imagery is an important kind of data source. MOD09A1 is an appropriate one, since this imagery provides an 8-day temporal resolution at 500-meter of spatial resolution. The general science data set of MOD09A1 is shown from Table 2-1:

Table 2-1. MOD09A1 General Characteristic

Temporal Coverage	February 24, 2000 – now
Area, Resolution	~10 x 10 lat/long, 500 meters
File Size, Data Format	~64 MB, HDF-EOS
Projection	Sinusoidal
Dimensions	2400 x 2400 rows/columns

Source: (Survey, 2015)

Besides, MOD09A1 also provides 7 bands of surface reflectance; three of which are suitable to calculate three indices (NDVI, NDWI, and NDDI.) These indices basically need bands of: Band 1 (620 – 670 nm) for red, band 2 (841 – 876 nm) for NIR and band 7 (2,105 – 2,155 nm) for SWIR. Expressed on figure 2-2 is the surface response in different spectral ranges

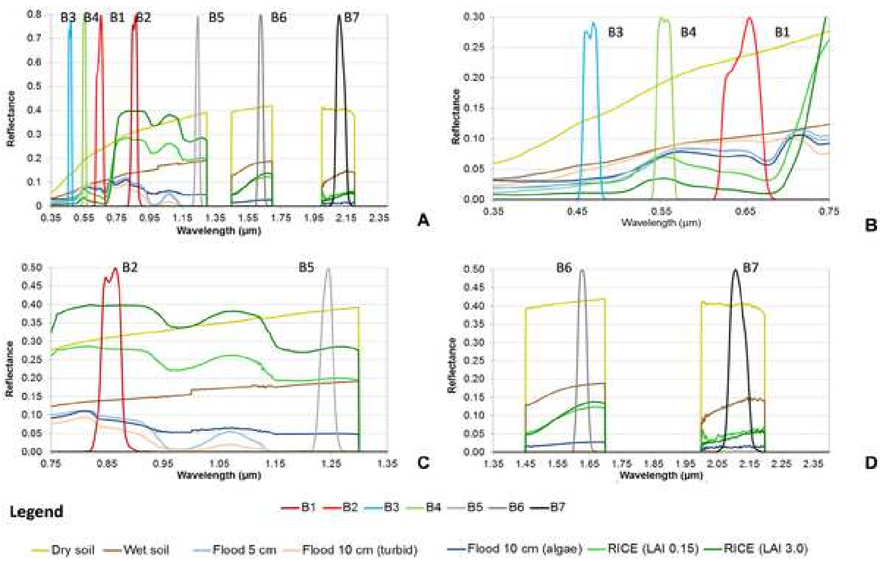


Figure 2-2 Surface responses at different spectral ranges: (a) all range: 350–2500 µm, (b) visible: 0.35–0.75 µm, (c) NIR: 0.75–1.35 µm, (d) SWIR: 1.4–2.5 µm

Source:

(http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0088741)

2.3 MODIS TERRA "MOD09A1" Images Processing

2.3.1 Indices Calculation Using Formula

The Normalized Difference Vegetation Index (NDVI) expresses the photosynthetic active vegetation greenness. It can be used to detect extreme periods when agricultural crops are affected by moisture deficit (Gu et al., 2007; Ryu et al., 2011). NDVI uses the reflectance values from the red band and the Near Infrared (NIR) band. The formula for NDVI is:

$$NDVI = \frac{(NIR\ band - Red\ band)}{(NIR\ band + Red\ band)}$$

The Normalized Difference Water Index (NDWI) expresses the water content of vegetation (Gu et al., 2007; Ryu et al., 2011). NDWI uses the reflectance values from the Near Infrared (NIR) band and the Shortwave Infrared (SWIR) band. The formula for NDWI is:

$$NDWI = \frac{(NIR\ band - \mathrm{SWIR}\ band)}{(NIR\ band\ +\ \mathrm{SWIR}\ band)}$$

NDDI combines the parameters of vegetation greenness (NDVI) and vegetation water-content (NDWI). Similar to the other two indices, NDVI and NDWI, the value of NDDI ranges between -1 to +1. Yet in NDDI, a higher value indicates a drier condition. The formula for NDDI is (Gu et al., 2008):

$$NDDI = \frac{(NDVI - NDWI)}{(NDVI + NDWI)}$$

2.3.2 Smoothing (Upper Envelop) the Noise in Hyper-temporal Images Using TIMESAT

Cloud cover in the time-series images could be reduced by applying the filter of adaptive Savitzky-Golay method using TIMESAT (NRS) Package, run in ENVI Software. Figure 2-3 shows the cleaning effect to reduce the atmospheric noise, so that the harmonic profile getting smoother (Jönsson & Eklundh, 2002).

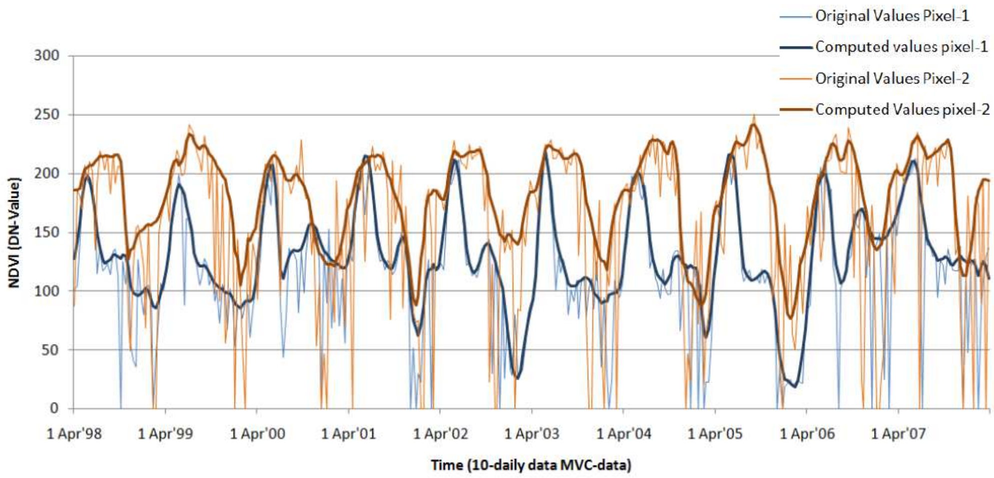


Figure 2-3 Smoothing Effect (Before and After Applying Upper Envelop Filter) to Reduce the Noise in Hypertemporal Images Using TIMESAT
Source: (K. (C. A. J. M. . de Bie & Skidmore, 2010)

2.3.3 ISODATA (Iterative Self-Organizing Data Analysis)

ISODATA is one of the methods in unsupervised classification in ENVI and ERDAS Imagine. Unsupervised classification performs more automatically by computer-controlled (no help from ground or field data) than supervised classification that needs assistance from the specified training samples ("Erdas Imagine: Supervised classification," n.d.).

ISODATA assigns a pixel value into one class, based on certain criteria. This pixel clustering have several purposes, e.g. related to the application in agriculture (to generate crop variability on cropping pattern, cropping calendar, crop type, etc) (Asilo et al., 2014).

For clustering, ISODATA performs an algorithm of minimum spectral distance (Minimum Euclidean Distance) of the closest class center, repeated in iterative process to calculate class' average. It starts from either an assigned set or arbitral class means. Then the iteration runs to recalculate statistic until the mean values of those clusters are changed for new class. New class is created either after the iteration process reaches the maximum pre-defined number (50 iterations) or the unchanged pixels reach a maximum percentage (C. a. J. M. De Bie et al., 2008).

Therefore, ISODATA could be used to simplify the abundant information from multi-temporal images. However, the tricky part is that ISODATA may take into account the information from several pixels into a larger spatial unit by spatial aggregation (see Figure 2-4). This would be a challenging part, once the analyzed locations have only a little area extent, because this aggregation may mix-up the spatial information from several pixel values.

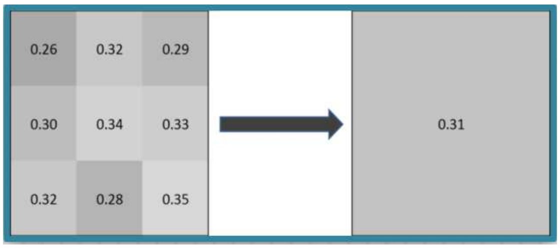


Figure 2-4 Spatial Aggregation to Simplify Mean Values from Several Pixels (FAO, 2011a)

2.4 Crop Growing Season of Rain-fed Paddy Field

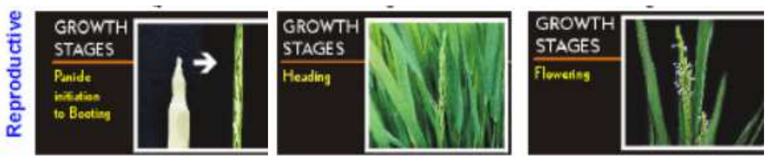
Crop phenology is corresponded to the period of crop's life stages. This life cycle is related to the seasonal influence from climatic condition (e.g. rainfall and temperature). Crop stages are differed from one type to another type of crops.

For rain-fed paddy field, the life stage takes about 105 – 120 DAT (Days After Transplanting) from the initial or seedling stage to harvesting stage. The phases of life stage could be divided into:

- Phase of Vegetative (25 – 40 DAT, takes about 40 – 60 days):
  - Stage of seedling (0 – 20 DAT) that is a transplantation phase on the prepared field
  - Stage of tillering (20 – 30 DAT) that is once the seeds are growing and the leaves are developing
  - Stage of stem elongation (30 – 40 DAT) is when the paddy is growing higher

Source: (International Rice Research Institute, 2007)

- Phase of Reproductive Stage (40 – 60 DAT, takes about 30 days):
  - Stage of panicle, that is an initiation booting
  - Stage of heading
  - Stage of flowering (15 – 20 days)



Source: (International Rice Research Institute, 2007)

- Phase of Generative or Ripening (60 – 105 DAT, takes about 30 days):
  It is the phase that has been affected by the rainfalls and temperature. Dry periods and high temperatures may shorten this phase, while wet periods and low temperatures may lengthen it. This phase encompasses the stage of milk (60 – 80 days), and the stage of dough (80 – 105 days)

Source: (International Rice Research Institute, 2007)

- Mature Stage / Harvesting Stage (105 – 110 DAT, takes ± 10 – 20 days)

Source: (International Rice Research Institute, 2007)

Crop calendar is the integrated information about planting season, provided by official government. Crop calendar gives several information, e.g.: the estimation of planting time; the area extent of planted field in a particular region; the local farming activities (needs for fertilizer and seeds); and the potential hazard (flood, drought, and plant scourge due to pest or disease). Crop calendar provides the local-level information (usually until sub-district level), corresponds to the geographical condition and seasonal variability that affect the crop's planting time and its life length.

In reality, the estimation of planting time could be shifted, related to for example: the condition of rainfall, changing in crop varieties, or farming practices. Dry spell is an example of this abnormal condition. It is the lag of the rainy season due to the elongated dry days. This delay could affect the crop cycle length as well as the yield productivity, though the effect would not be as devastating as the effect from drought occurrence (Barron, Rockström, Gichuki, & Hatibu, 2003). This lag in planting phase could be detected from the seasonal graph of indices profile, derived from the multi-temporal images (see figure 2.5).

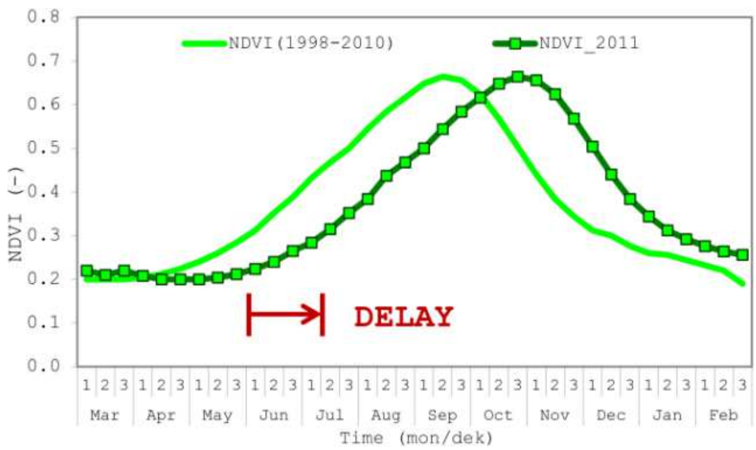


Figure 2-5 Delay on the Growing Season, Derived from the NDVI Time Series (FAO, 2011b)

2.5 Temporal Graph of Indices Histogram for the Rendition of Normal Condition and Anomaly Occurrence

The normal behavior and anomaly occurrence of the photosynthetic active vegetation greenness could be retrieved from the rendition or interpretation of the seasonal (temporal) graph of indices profiles (e.g. NDVI, NDWI, NDDI, etc.).

2.5.1 Seasonal (Temporal) Graph of Indices Profile

Temporal graph presents the dynamic characteristic of the photosynthetic active vegetation greenness on certain period. Indices profiles were derived from the value extraction of certain pixel of the multi-temporal images. The profile therefore carries the spatial and multi-temporal information from one pixel that shows the dynamic behaviour through certain period (e.g. during Crop Growing Season). Figure 2-6 shows the example of temporal graph of NDVI dynamic values from a certain pixel.

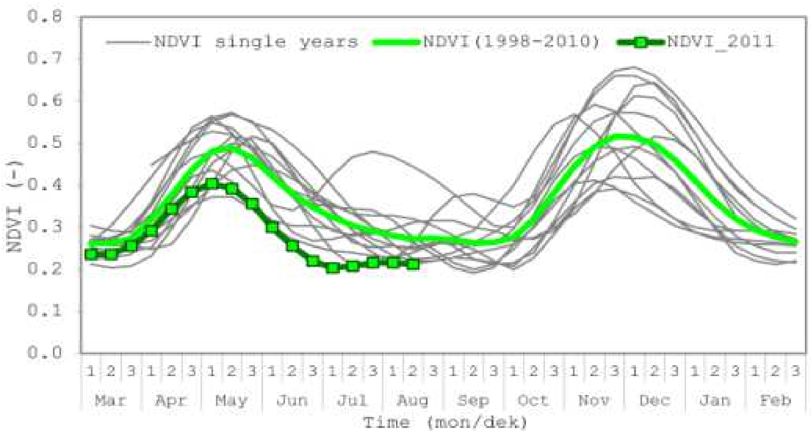


Figure 2-6 Temporal Graph of NDVI Dynamic Values, Retrieved from One Pixel (FAO, 2011b)

In paddy life stage, the Crop Growing Season (CGS) has association with the vegetation greenness (see Figure 2.7). The greenness condition are staging up until the paddy phase of flowering (Mosleh, Hassan, & Chowdhury, 2015). In this research, the Crop Growing Season (GCS) of the rain-fed paddy field are used as base period to generate the indices profile. Thus, it normally takes about 60 – 65 days for rain-fed paddy to reach the greenest condition.

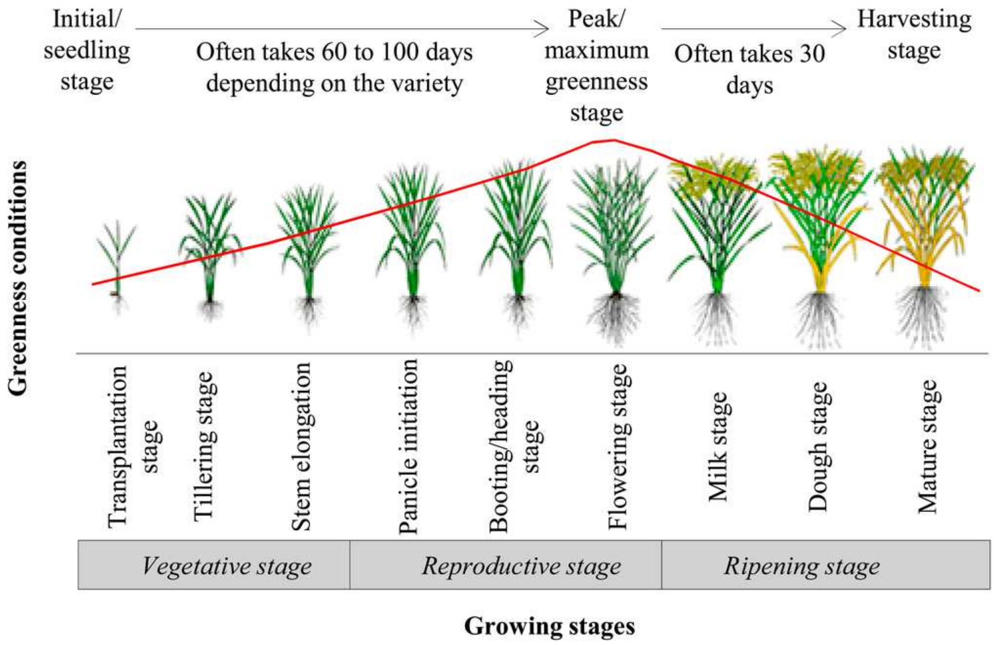


Figure 2-7 Paddy Stage Associated to Its Greenness Condition

Source: (Mosleh et al., 2015)

2.5.2 Parameters of Seasonal (Temporal) Graph

Related to the temporal graph parameters, the paddy growing season could be presented in a seasonal graph as in figure 2.8. The graph shows several parameters from indices histogram (Jönsson & Eklundh, 2014), i.e.:

- "a" and "b". "a" expresses the onset or the beginning of growing season (the emergence of crop), while "b" expresses the end of growing season (the harvesting stage). These parameters are defined by the 10% of the distance between the base-value "d" with the maximum-value "f".
- "c" shows the Length of Cycle (LOC) that is the distance between the start-end of growing season;
- The base value "d" is the lower values before the onset and the end of growing season.
- "e" and "f" express the peek parameters. "e" shows the middle season period, while "f" is the maximum value of indices (the end of vegetative phase or the flowering period);

– The amplitude “g” shows the difference between the maximum-minimum values of indices. Therefore, amplitude shows the variation of temporal indices values in years.
– “h” and “i” are the first and second integral, respectively. “h” expresses the temporal active vegetation greenness, while “i” expresses the vegetation’s net production.
– Green-up rate expresses the staging-up speed from the paddy emergence or the paddy establishment. It is the halfway points between the minimum-maximum values. This rate of increase is expressed by the ratio between the amplitude and the time period from start to middle season.

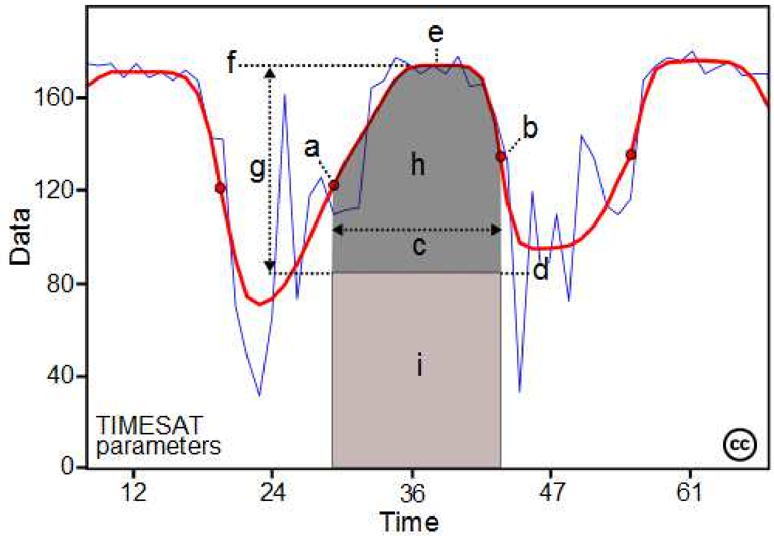


Figure 2-8 Seasonal Parameters: (a) onset season, (b) end of season, (c) season length (length of cycle), (d) base value, (e) middle season, (f) maximum value, (g) amplitude, (h) first integral area, (i) second integral area
(Jönsson & Eklundh, 2002)

2.5.3 Rendition of Normal Condition and Anomaly Occurrence from Seasonal Graph

Anomaly in terms of agricultural drought corresponds to indices values are expressed as a negative deviation from the normal condition. It may indicate the low performance of the photosynthetic active vegetation greenness. This suppressing disturbance could affect the crop productivity.

The dynamic behaviour of indices values over certain years could be calculated for its mean values to correspond a norm value as an average condition. The average calculation should be considered to be quantified within the similar period (e.g. at Crop Growing Season, wet or dry season, decadal period, etc) of the reference years. Therefore, the normal condition could be identified by taking into account the dynamic behaviour from the previous years' average values on the same season as shown in the formula of:

$$Normal\ Condition = Mean\ Values\ of\ Previous\ Years\ at\ the\ same\ season$$

Anomaly in terms of agricultural drought identification is basically a value deviated from the normal behaviour, as expressed in average condition. Anomaly could be identified in three ways (FAO, 2011b)

- Absolute Anomaly

  Anomaly is detected from the decreasing values of two different references, where the current value is subtracted by the multi-annual mean value of previous years. This is the easiest way to calculate anomaly, as seen from the function below:

  Absolute Anomaly = Current Value (year x) – Normal Condition Value

- Relative Anomaly

  Anomaly is expressed as a percentage of the normal value. Current value that is < 100% is identified to be the anomaly from a normal level, as expressed from the function below:

$$\textit{Relative Anomaly} = \frac{100\ x\ Current\ Value}{Normal\ Condition\ Value}$$

- Standardized (Z-score) Anomaly

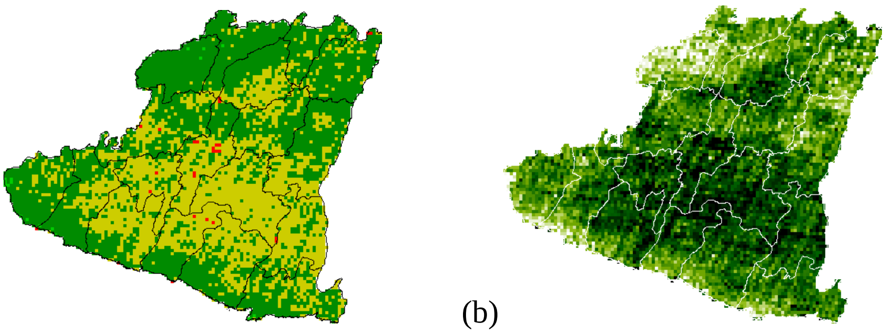
  Anomaly is indicated by the variability between years, where the number of standard deviations current is expressed below or above the normal condition. The formula is:

$$\textit{Standardized (Z-score) Anomaly} = \frac{(Current\ Value - Normal\ Condition\ Value)}{Standard\ Deviation\ of\ Previous\ Years}$$

2.6 Unit Analysis of Indices Profile

To interpret the indices profile (NDVI and NDDI), it firstly takes a consideration to choose whether using the unit analysis that is a pixel-based or a class-based level. Pixel-based generates the indices values from selecting the exact locations; while class-based basically selects the locations, based on unsupervised classification from the ISODATA.

By means of this, there are several pros and cons to be considered, especially in terms of the abundant information retrieved from the hyper-temporal indices. By using the class-based, the mixed information in one pixel related to landcover types is quite an issue. It is because it may also aggregate some landcover types dissolved into one class. However, using the original pixel-based values is quite an issue regarding to its massive information, extracted over the hyper-temporal imageries (see Figure 2.9).



(a) (b)

Figure 2-9 Spatial Representations of the NDDI Values in District of Gunungkidul, on February 7th, 2000 (DOY 2000049), by (a) classed-based of 9 NDDI classes, and (b) pixel-based of 255 DN Values
Source: MOD09A1 Processing, 2014

2.7 Relevant Studies

Some previous studies regarding agricultural drought using satellite-based indices (primarily NDDI and NDVI) are mentioned below:

1. Research by Gu et all. (2007) to assess NDDI derived from MODIS imageries for grasslands. NDDI was found to have more vigorous response to drought than the use of solely NDVI (The Normalized Difference Vegetation Index) or NDWI (The Normalized Difference Water Index) (Gu et al., 2007).
2. Drought pattern on crop management was explored in Northeastern Thailand in 2001 – 2008, by using NDVI and NDDI from Terra-MODIS (Mongkolsawat et al., 2009). The research found the use of this indices to be effective to assess drought, since using climatic data has challenge in spatial coverage.
3. NDDI research, conducted by Renza et all. (2010) on different vegetation types using Landsat imagery. NDDI also indicated a stronger response to drought than the use of NDVI and NDWI. The values of NDVI and NDWI are strongly correlated to the vegetation greenness, while NDDI indicates the dryness period over an area (Renza et al., 2010).
4. Research to estimate drought severity by using NDVI on photosynthetic activity and NDDI on dryness of vegetation was also undertaken in the Iberian Peninsula from 1999 – 2009 (Gouveia, Bastos, Trigo, & DaCamara,

2012). Result found that NDDI was an effective formula to estimate drought due to its combination on vegetation and water conditions.

5. Another NDDI and NDVI research to assess perennial drought was conducted in arid and semi arid Baringo County, Kenya (Kapoi & Ndegwa Mundia, n.d.). In this research drought assessment was validated by meteorological data from NOAA-AVRHR to determine variability of rainfall

3. STUDY AREA

3.1 Location and Administration of Study Area

District of Gunungkidul is located in the Eastern part of the Province of Yogyakarta Special Region. It is located on 7°46' – 8°09' S and 110°21' – 110°50' E. District of Gunungkidul has a total area extent of 1,485.36 Km^2 or covers ± 46.63% of Province of Yogyakarta area (BPS, 2013a). This district is consisted of 18 sub-districts and 144 villages (See Figure 1-1).

3.2 Soil Type

Generally, District of Gunungkidul has several soil types with low drainage quality and a relatively thin-soil layer. This area is mostly karstic by limestone and marl (especially in Southern part). Figure 3-1 shows that there are also entisols (acid litosols and rensina), alfisol (mediteran and latosol), as well as vertisols (grumosols); with pH-value ranges from 5.5 – 7.5 (Enryd, 1998).

In northern part of Gunungkidul district, the material is a volcanic origin, though there are also steep limestone-ridge areas (Enryd, 1998). This area is dominated by litosol and latosol with volcanic-host rock. In center part, the area is covered by the association of red mediterranean and black grumosol with limestone material; so that when drought happens, this area could still have water storage though the surface river could possibly be dried off (Local Government of Gunungkidul District, 2014).

Related to the agricultural drought, soil types have special characteristic that may affect the agricultural drought. Soil texture is related with its moisture, especially corresponds to the infiltration and permeability. Coarse sand with grain particle has a larger pore (e.g. litosol). This texture will easily pass-through the water into deeper layer and hardly hold the water. This condition makes it susceptible to agricultural drought. Meanwhile, silt and clay soil with smooth and fine texture has a smaller pore therefore can retain the water more (e.g. latosol, rendzina, mediterran, and grumosol) (Dudal & Supraptoharjo, 1982; FAO, UNESCO, & ISRIC, 1997; USDA, 1977).

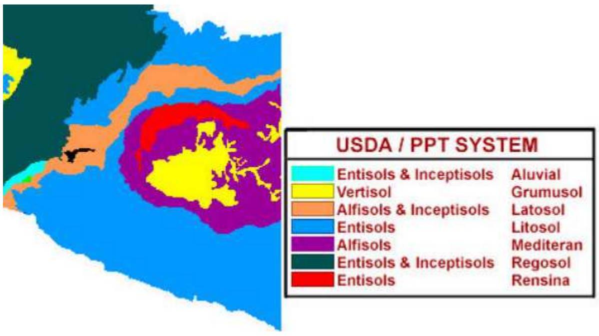


Figure 3-1 Soil Type Map of Gunungkidul District
Source: (Enryd, 1998)

3.3 General Morphology and Geo-hydrological Condition

From its topographical condition, the height of Gunungkidul ranges between 0 – 800 meter above mean sea level (a.m.s.l.) with most of its area lies in height range of 100 – 500 meter a.m.s.l. (see figure 3-2). Moreover, it has three main morphological differences from the northern part to the southern part:

- Firstly, the north zone (Batur Agung). It is a hilly area with height ranges from 200 – 700 meter a.m.s.l. Geo-hyrodrological type of this area is a scarce groundwater (see figure 3-3). In this area, underground water is usually found at 6 – 12 meter. About 6 sub-districts are located at this area (Patuk, Gedangsari, Nglipar, Ngawen, Semin, dan Northern Ponjong).
- Secondly, the center zone (Ledok Wonosari). This is a basin area with height ranges from 150 – 200 meter a.m.s.l. Water table is usually found at 60 – 120 meter. About 5 sub-districts are located at this area (Playen, Wonosari, Karangmojo, Center part of Ponjong, and Northern Semanu).
- And lastly, the southern zone, Gunung Seribu (Duizon gebergton or Zuider gebergton). It has height ranges from 0 – 300 meter a.m.s.l. It is a karst zone (conical limestone or kegelkarst type) that has many underground rivers. About 10 sub-districts are located at this area (Saptosari, Paliyan, Girisubo, Tanjungsari, Tepus, Rongkop, Purwosari, Panggang, Souhtern

Ponjong, and Souhtern Semanu) (Local Government of Gunungkidul District, 2014). The geo-hydrological type of the center and southern zone are mostly covered by a highly-gap aquifer (see figure 3-3).

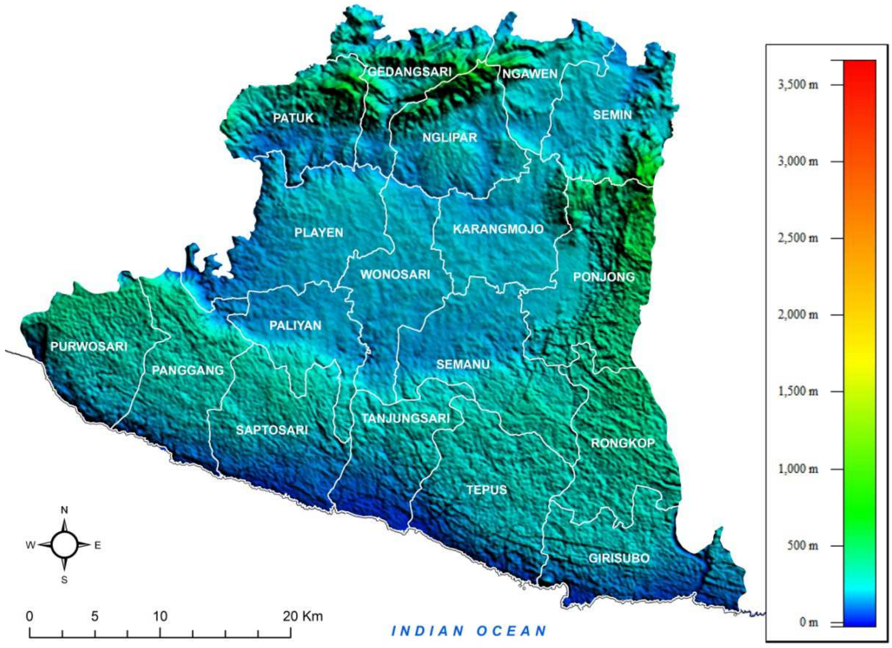


Figure 3-2 General View of Gunungkidul Morphology
Source: SRTM

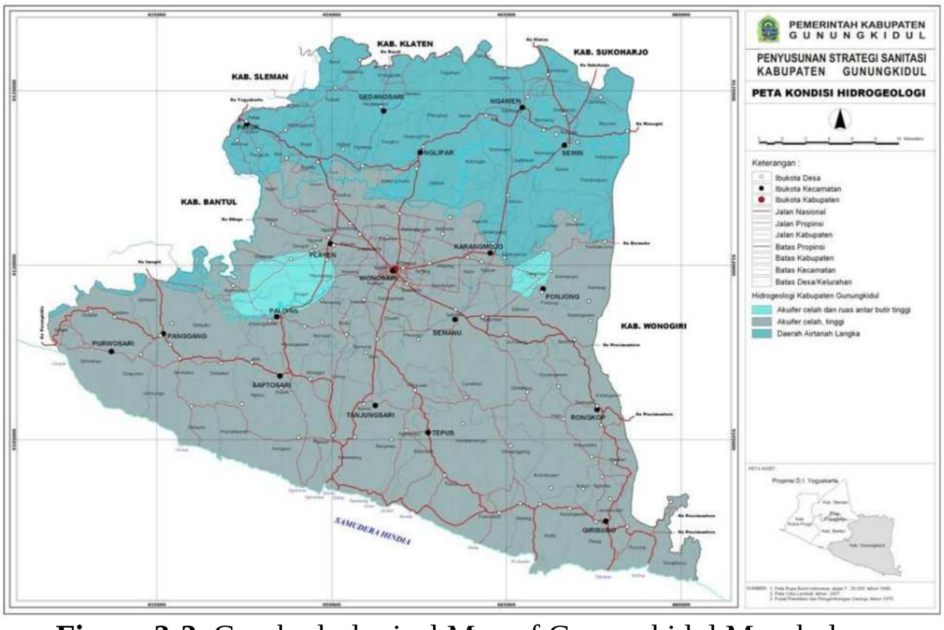


Figure 3-3 Geo-hydrological Map of Gunungkidul Morphology
Source: (Regional Planning Board of Gunungkidul, 2006)

3.4 Climate

Gunungkidul District has a tropical cimate. Generally, the mean annual rainfall is 1,900 – 2,100 mm/year, with the total rain days are 88 – 103 days/year. Wet months stay for 7 – 8 months (October – April), while dry months stay for 4 – 5 months (May – September). Figure 3-4 shows the highest rainfall (2,501 – 3,500 mm/year) that occurs in the Southern part of area (Local Government of Gunungkidul District, 2014).

Figure 3-5 shows the monthly rainfalls intensity (top) as well as the number of rain days (bottom) over years in the District of Gunungkidul. The rainfall peak usually happens in December – February, while the lowest rainfall intensity happens in June – September. Besides, the highest number of rain days was in 2010 (126 rain days), while the lowest number was in 2002 (61 rain days) (BPS, 2002, 2006, 2009, 2013b).

The temperature ranges from 23.2 – 32.4 °C; while the humidity ranges between 80 – 85 %, varied majorly by the seasonal period. The highest humidity happens in January – March, while the lowest happens in September (Local Government of Gunungkidul District, 2014).

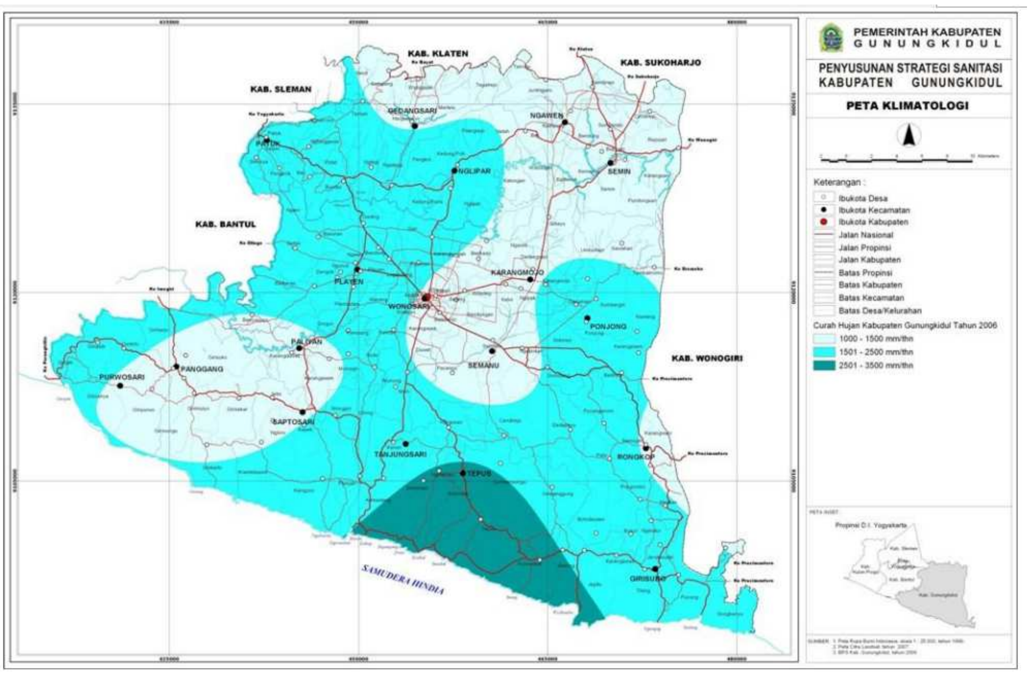


Figure 3-4 Rainfall Map of Gunungkidul District
Source: (Regional Planning Board of Gunungkidul, 2006)

Figure 3-5 Monthly Rainfalls in mm (top) and Number of Rain Days (bottom), in District of Gunungkidul, Year 2000 - 2013
Source: (BPS, 2002, 2006, 2009, 2013b)

3.5 Agriculture in Gunungkidul

3.5.1 Rice Field Area in District of Gunungkidul

In year of 2013, the harvested area from rain-fed paddy field in Gunungkidul District reached 43,361 Ha. Figure 3-6 shows the location of the rain-fed paddy field area by sub-district. The irrigated rice field has a total area extent of 2,355 Ha, while the rain-fed rice field has an area of 5,510 Ha (Local Government of Gunungkidul District, 2014).

Figure 3-7 shows the comparison of the harvested area from rain-fed paddy field (Ha) with the area extent of Sub-District. The graph shows that sub-district of Wonosari had the most extensive harvested area of rain-fed paddy field

(3,103.62 Ha), while Gedangsari had the lowest with 547.76 Ha. From the area extent ratio between the harvested areas of rain-fed paddy field to its sub-district; Wonosari has the highest ratio of 41.10, while Gedangsari has only 8.04.

Figure 3-6 Rain-fed Paddy-Field Area of Gunungkidul District
Source: Regional Planning Board of Gunungkidul, 2006 & Landsat 8 Processing

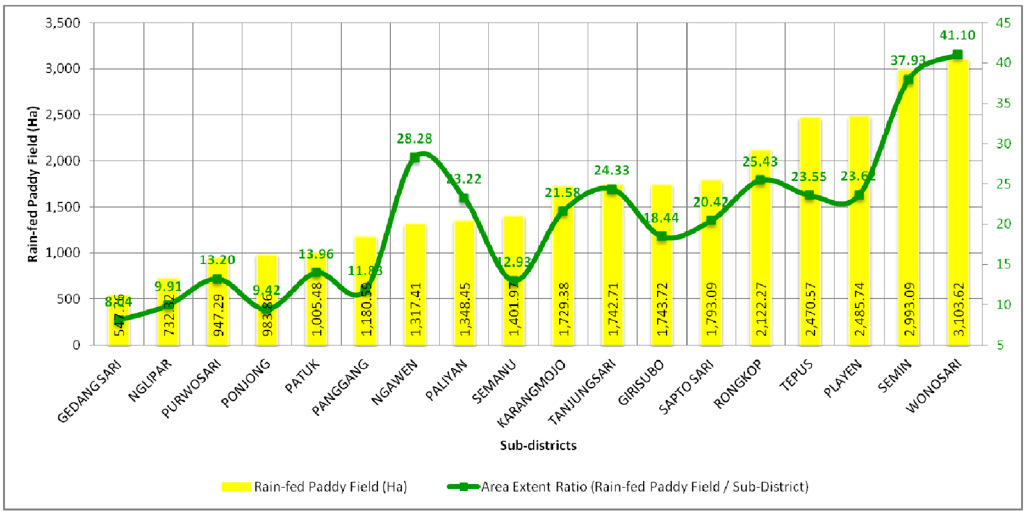


Figure 3-7 Comparison of the Rain-fed Paddy Field (Ha) to the Area Extent of Sub-District (Ha)
Source: (BPS, 2002, 2006, 2009, 2013b)

3.5.2 Cropping Calendar

Best planting time is related to the seasonal condition (rainfall intensity). In Gunungkidul area, rainy season usually happens in October – March, while the dry season happens in April – September.

From the cropping calendar in District of Gunungkidul (see Table 3-1), the 1st planting normally happens between the 2nd period of October until the 2nd period of November. While for the 2nd planting generally happens between the 2nd period of February until the 2nd period of March (Ministry of Agriculture, 2014). Farmers usually start preparing the field in the early October for the 1st planting, and in the early February for the 2nd planting.

However, related to the meteorological conditions (e.g. the rainfall intensity and the onset of rainy season), this planting period could be shifted from that normal period. Dry spell is an example of an abnormal condition. It is the lag of the rainy season due to the elongated dry days. Related to drought, dry spell could bring a potential damage to the crops, though the effect would not be as devastating as the effect from drought occurrence (Barron, Rockström, Gichuki, & Hatibu, 2003).

Table 3-1. Paddy Planting Calendar in District of Gunungkidul, year 2014

Month	Jan				Feb				Mar				Apr				May				June				July				Aug				Sept				Oct				Nov				Dec			
Week	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Paddy Growing Season	G		H						P		S		V				G				G		H										P		S		P		S		V				G			
Rainfalls (mm)	326.21				319.17				243.09				191.28				109.65				59.63				49.41				15.03				33.14				81.43				178				288.29			

P: Field Preparation; **S:** Seedling; **V:** Vegetative Phase; **G:** Generative Phase; **H:** Harvesting

Source: (Ministry of Agriculture, 2014)

The typical rain-fed paddy variety that was planted in District of Gunungkidul is “Ciherang” with the age of 107 – 115 days (15 – 16 weeks). But since 2012, the variety had been changed into “Situ Bagendit” with the age of 110 – 120 days (15 – 17 weeks).

In paddy planting stage, there are three growing phases; (1) vegetative: 0 – 60 days, (2) generative: day 60 – 90, (3) harvesting: day 90 – 120. Vegetative phase starts from the planting days until the paddy leaves are developed and the paddy is higher. Generative phase starts from the appearance of paddy's grain until the flowering. (Center for Soil & Agroclimate Research, 2004)

The Crop Growing Season (CGS) happens in the vegetative phase. Related to the MOD09A1 time-series imageries, the CGS therefore could be detected by identifying the highest values of NDVI. NDVI could express the photosynthetic active vegetation greenness that is sensitive to pinpoint the vegetative phase of paddy planting stage (see Figure 2-7).

3.5.3 Rain-fed Paddy Productivity in District of Gunungkidul

Spatially, statistic of crop will help identifying the variation of crop performance in different areas; that will be beneficial to monitor and assess crop production (Khan, De Bie, Keulen, Smaling, & Real, 2010). Figure 3-8 shows the paddy production by Sub-district (Ton) in Gunungkidul District, year 2013. It shows that the paddy production in Sub-districts of Purwosari, Tanjungsari, and Tepus was <10,000 tons, while in Sub-districts of Patuk, Semin, Karangmojo, and Ponjong was >20,000 tons (BPS, 2014).

In District of Gunungkidul, there is a typical agricultural system of *tumpangsari* practice. It is an intercropping system, especially in a rain-fed paddy field that is planted with the secondary crops, e.g.: maize or soybean. Therefore, the agricultural commodities yields are not only produced from the paddy (wet-land and dry-land paddy), but also from dry-field crops (maize, cassava, sweet potatoes, peanuts, and beans). However, the agricultural productivity in this research will be focused only on rain-fed paddy crop.

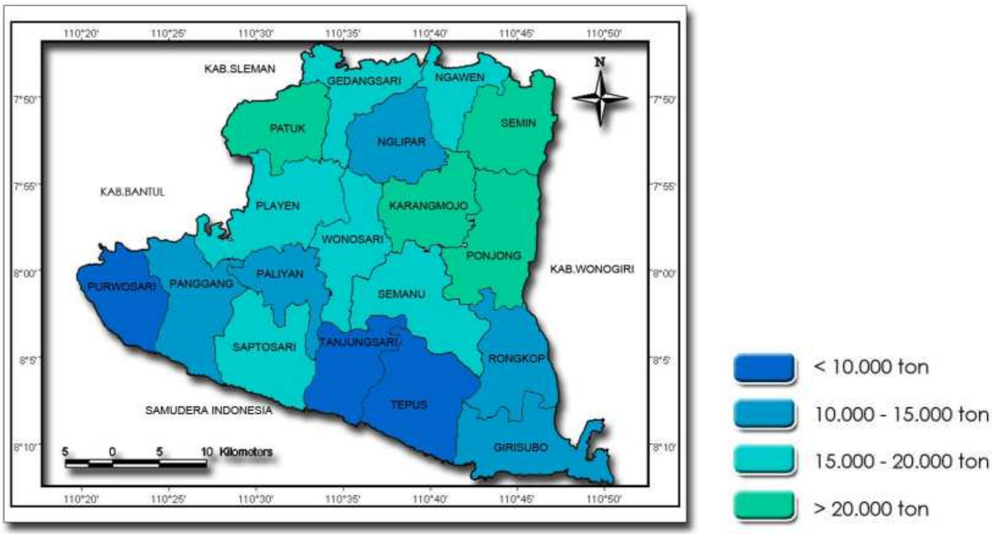


Figure 3-8 Map of Paddy Production by Sub-district (Ton) in Gunungkidul District, 2012
Source: (BPS, 2013b)

Productivity measures the production efficiency by comparing the yield production to its area extent. Figure 3-9 shows the productivity of the rain-fed paddy crop in District of Gunungkidul, from year of 1990 – 2013. It shows an increasing trend in about 20 years. The lowest productivity happened in 1990 (24.92 Qu/Ha), and the highest happened in 2012 (48.44 Qu/Ha). The annual mean productivity from 1990 – 2013 was 34.05 Qu/Ha.

Figure 3-9 Rain-fed Paddy Productivity in District of Gunungkidul, Year 1990 - 2013
Source: (BPS, 2014)

Figures 3-10 expresses the rain-fed paddy productivity average in District of Gunungkidul, by sub-districts within 1997 – 2013. Spatially, the map shows several sub-districts that relatively have a lower rain-fed paddy productivity than any others sub-districts, e.g. Patuk, Purwosari, Panggang, Saptosari, and Tepus. This is related to the physical condition of those sub-districts; where Patuk is a hilly area in the Northern part of Gunungkidul District, while the three others are karstic area in the Southern part of Gunungkidul District.

Figure 3-10 Map of Rain-fed Paddy Productivity (Quintals/Hectare)
By Sub-district, Years of 1997 – 2013
Source: data processing

3.5.4 Agriculture Contribution to GRDP (Growth Regional Domestic Product)

GRDP is an indicator to the development of economic in certain region and period. GRDP expresses the grand total of the value-added production from goods and services. In 2013, GRDP of Gunungkidul District reached 8.902.405 Million Rupiahs where agriculture sector gave the highest contribution as it has always been over years (BPS, 2014).

In 2013, Agriculture sector contributed 36.49% (Rp. 1,329,212 Million) as the highest contributor. In 2013, rain-fed paddy field gave 67.50% (195.563,18 tons) from the whole total paddy production (289,521 tons) (BPS, 2014).

3.6 Drought in District of Gunungkidul

Generally, drought has been a challenging case in the District of Gunungkidul, Province of Yogyakarta Special Region. This area has been experiencing a yearly agricultural drought. In 2011, fifteen (15) sub-districts out of eighteen (18) sub-districts were experienced a wide spreading drought (from ten sub-districts in 2010). In 2011, drought disaster had caused thousands of residents in 171 hamlets needed a clean water supply, where sub-district of Ngawen and Panggang had experienced the worst drought. This condition affects the agriculture activities and its yield where both of local and national mass media has been reporting drought occurrences in most parts of this area. (http://news.okezone.com/, http://krjogja.com/, http://www.data1.sapa.or.id/

4. MATERIAL AND METHODOLOGY

4.1 Material Dataset

Related to the research, the dataset needed were:

1. Modis Terra MOD09A1 (8-day temporal resolution for 500 meter spatial resolution), within a 14-years period (2000 – 2014). The bands used are: Band 1 (620 – 670 nm) for red, band 2 (841 – 876 nm) for NIR and band 5 (1,230 – 1,250 nm) for SWIR. Source: LP DAAC.
2. Crop statistics of rain-fed paddy productivity by sub-districts, year 2000 – 2014. Source: Local Statistics of Gunungkidul District, and Department of Agriculture and Horticulture of Gunungkidul District
3. Landsat 8 for path/row: 120/65 (June 24th 2013), 119/60 (October 07th, 2013), and 120/66 (September 28th, 2013); from LAPAN (National Institute of Aeronautics and Space)
4. Landcover map of District of Gunungkidul, year 2006. Source: Bappeda (Agency of Regional Development Planning) and the Geospatial Information Agency (BIG)
5. Sub-district Border from Bappeda (Agency of Regional Development Planning) and Local BPS (Central Bureau of Statistics)
6. Rice Crop Calendar from the Ministry of Agriculture
7. Soil type of Gunungkidul Area from Puslitanak (Soil and Agro-climate Research Center)
8. Rainfall Data year 2000 – 2014 from BMKG (Indonesian Agency for Meteorology, Climatology and Geophysics) and Local Statistics of Gunungkidul District

4.2 Methodology

The conceptual framework could be seen from Figure 1-3 in section 1.4.1. It illustrates how the research was conducted. This research would primarily generate the satellite-based indices of NDVI and NDDI from the MOD09A1 time-series images. The indices profiles were extracted on the rain-fed paddy field, within a crop growing seasons over a 14-year period of study (2000 – 2014). The dynamic behavior of these two indices was analyzed through the seasonal histogram parameters, to indicate the agricultural drought happened in District of Gunungkidul.

The analysis of seasonal histogram was based on the indices' graph parameters (Jönsson & Eklundh, 2014) as previously mention in section 2.5.2, i.e.: (1) the onset and the end of paddy growing season, (2) the length of paddy life cycle, (3) the amplitude for the variation of temporal indices values in years, and (4) the green-up rate of the paddy staging-up speed. After that, the agricultural drought was indicated from the rendition of the normal condition (average of previous years) and anomaly occurrence (negative deviation from normal condition) based on the dynamic behavior from seasonal histogram.

Then, the performance of these indices in indicating the agricultural drought was compared to the rain-fed paddy productivity in each sub-district. The comparison was done by using the correlation coefficient between the indices performance and rain-fed productivity to evaluate which index performs better as an agricultural drought indicator.

Basically, the research could be divided into five aspects: (1) Material and Dataset Collection, (2) MODIS TERRA MOD09A1 Processing, (3) Sampling Selection, (4) Analysis, (5) Fieldwork Verification., i.e:

4.2.1 Material and Dataset Collection

Data collection and preparation, as previously mentioned in point 4.1 of material datasets

4.2.2 MODIS TERRA "MOD09A1" Processing

The framework of this phase could be seen from Figure 1-4 in section 1.4.2. This phase explains how the MODIS TERRA "MOD09A1" was processed to generate the indices profiling, i.e.:

1. MOD09A1 hyper-temporal Images Stacking Over 14-years

MODIS MOD09A1 provides an 8-day temporal resolution since February 24th, 2000. Therefore the total numbers of stacked images used in this research were 658 multi-temporal images for a 14-years period of study.

2. Quantifying the NDVI and the NDWI.

The indices calculation was done by processing the stacked-MOD09A1 using ENVI Classic Software. The result was to generate the dynamic profile of NDVI and NDWI values over 14 years. The formulas of NDVI and NDWI are:

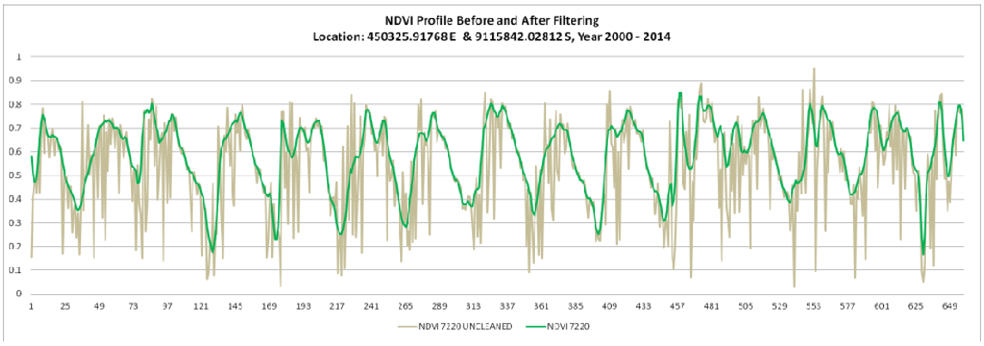
$$NDVI = \frac{(NIR\ band - Red\ band)}{(NIR\ band + Red\ band)}$$

$$NDWI = \frac{(NIR\ band - \mathrm{SWIR}\ band)}{(NIR\ band + \mathrm{SWIR}\ band)}$$

3. Hyper-temporal Images Filtering Using Adaptive Savitzky-Golay

This step was to apply the Adaptive Savitzky-Golay filter on the multi-temporal images. The filtering process was to clean the images from the cloud cover noise. Those time-series images were already contained the information of the calculated indices (NDVI and NDWI) values.

Figure 4.1 shows how the filtering process affects the profile smoothness. This profile was selected from a pixel, mostly covered by the rain-fed paddy field (450325.91768 E and 9115842.02812 S).



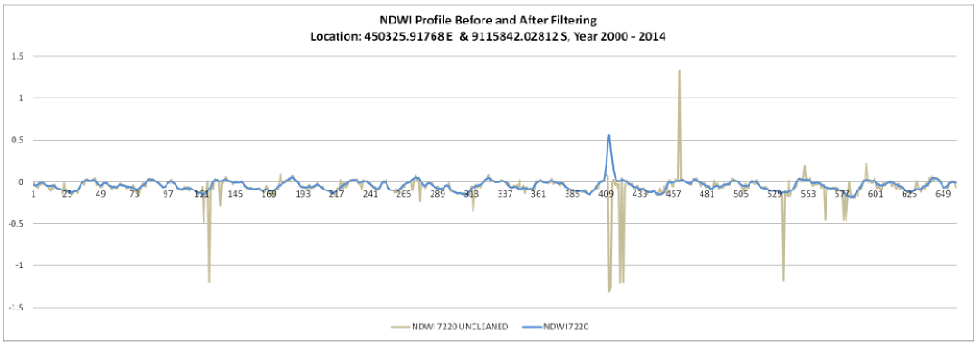


Figure 4-1 the Indices Profiles of NDVI (top) and NDWI (bottom), before and after filtering using TIMESAT. Pixel taken from the location of 450325.91768 E and 9115842.02812 S, Years of 2000 – 2014

4. Quantifying the NDDI

The NDDI calculation was done after the hyper-temporal NDVI and NDWI images were cleaned using TIMESAT. The result was to generate the dynamic profile of NDDI values over years. The formulas of NDDI was:

$$NDDI = \frac{(NDVI - NDWI)}{(NDVI + NDWI)}$$

5. Pixel-Based Level of Indices Profiling

The hyper-temporal profile was generated by selecting one pixel that represents a dynamic performance of paddy growing season, within a 14-years period of study. Firstly, it took a consideration to choose whether using the unit analysis of a pixel-based or a class-based level. Pixel-based generated the indices values from selecting the exact location, while class-based basically selecting the result of unsupervised classification from ISODATA.

By means of this, there are several pros and cons to be considered. For example in pixel-based, the abundant information of the hyper-temporal indices was inevitable. However, the indices profiling was easily pointed to the feasible rain-fed paddy location. While in class-based, the mixed information in one pixel (related to landcover types), was quite an issue.

To tackle this, the "pre-analysis phase" was done to get the overview about the rain-fed paddy field feasibility (location and its area extent), correspond to the MOD09A1 pixel-size. Therefore, the profile sampling would have been selected from locations that were properly observed. It was to assume that by the relatively small rain-fed paddy field area, this coverage was suitable for a pixel-based unit analysis of the moderate-scaled MOD09A1.

4.2.3 Sampling Technique for Indices Profiling

Sampling was used as site selection for extracting the indices profile; since presenting the indices profile for all pixels would not be proper. Sampling location was conducted to select the specific pixels in each sub-district that were feasible; especially related to the location and area extent of rain-fed paddy field corresponds to MOD09A1 pixel-size. The criteria for the selected samples were done through several steps:

1. Sample locations were from the mostly rain-fed paddy field. The rain-fed paddy field was derived from the Landsat-8 interpretation as well as from the landcover-map updating, to get the latest location of rain-fed paddy field.

2. Ratio calculation of rain-fed paddy field area in each sub-district. Related to the sub-districts as a unit analysis, this step was to get the overview of the rain-fed paddy field area extents in each sub-district. Figure 4-2 shows the ratio of rain-fed paddy field by sub-district. It shows that some of the rain-fed paddy area-extents are relatively small compared to its sub-districts area (i.e. Gedangsari,

Ponjong, Nglipar, Panggang, Semanu, Purwosari, Patuk, and Girisubo) that have the area extent of rain-fed paddy field that < 20%,.

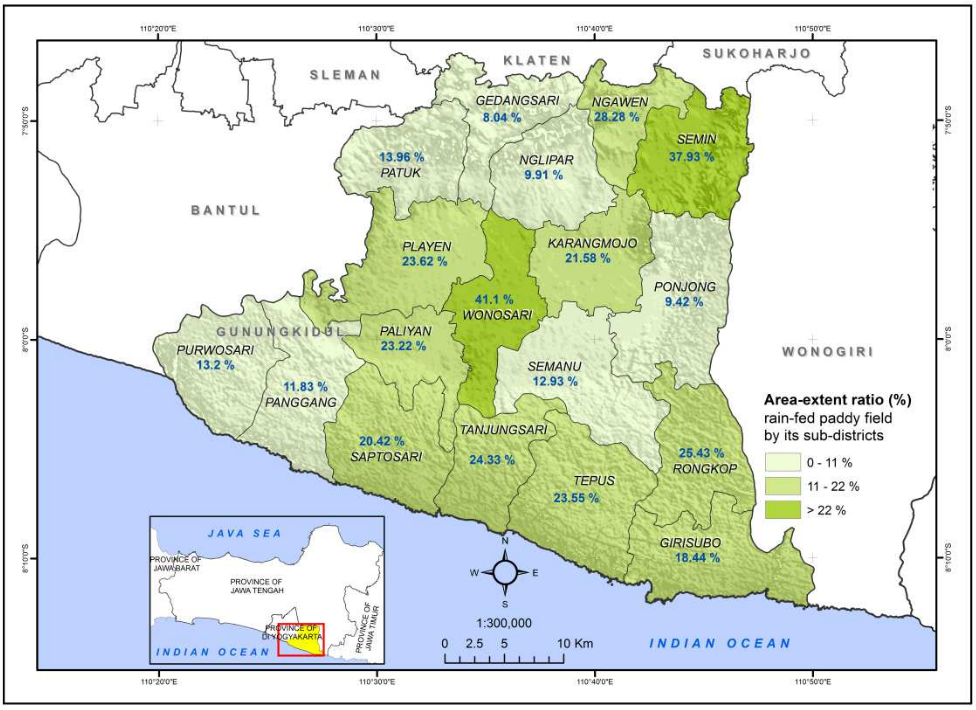


Figure 4-2 Area-extent ratio of rain-fed paddy field by its sub-districts
Source: Data Processing and Department of Agriculture & Horticulture of Gunungkidul District

3. The rain-fed paddy field areas overlaid by the MOD09A1 pixel size.

This was to get the overview about the rain-fed paddy field feasibilities (location and its area extent), correspond to the MOD09A1 pixel-size. It was to maximize the feasible pixels that had the information of photosynthetic activity, majorly from the rain-fed paddy crop.

However, there was a trickiness related to the rain-fed paddy coverage percentage within a MOD09A1-pixel size, in each sub-district. Several trial calculations had been computed to get the best rain-fed paddy coverage percentage in one pixel, in each sub-district (see Table 4.1).

Figure 4-3 suggests that the best number for rain-fed paddy field coverage was 70% in one MOD09A1 pixel-size, valid for 320 sample locations. However, this percentage had the 6 uncovered sub-districts that were considered to be not feasible, i.e. Purwosari, Girisubo, Saptosari, Tepus, Tanjungsari, and Rongkop (rain-fed paddy coverage was < 70%).

Table 4-1. Rain-fed Paddy Field Coverage (%) Corresponds to the Number of Pixels and the Uncovered Sub-District

Rain-fed Paddy Field Coverage (%) in one MOD09A1 pixel size	Number of Samples	Uncovered Sub-Districts
50%	665	1
55%	561	1
60%	469	2
65%	397	5
70%	320	6
75%	256	7
80%	193	8
85%	147	9
90%	108	10
95%	67	12

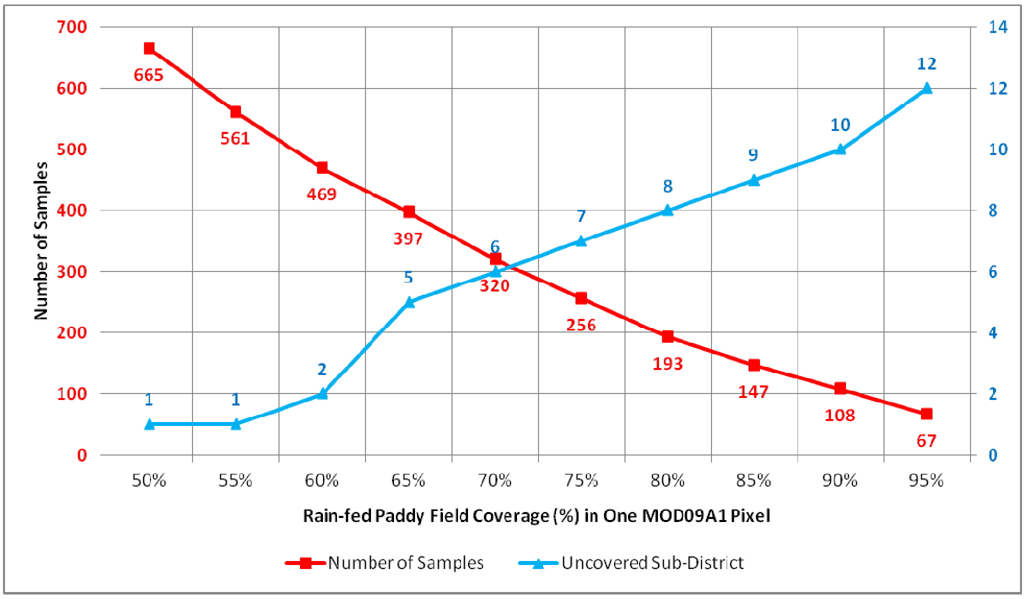


Figure 4-3 the area-extent ratio of rain-fed paddy field coverage (%), corresponds to the number of samples & uncovered sub-districts

4. Weighted-calculation of rain-fed paddy field area.

This was to analyze the more realistic amount of samples (since the ideal samples would have been 320 locations). Area-extent ratio classification had been made as a base to select the amount of feasible locations in each sub-district. The wider the area-extent of rain-fed paddy field in one sub-district, the more samples were selected on that particular sub-district. Table 4.2 shows the result of 50 selected samples locations from weighted calculation; while Annex-1 inscribes all 50 sample locations.

Table 4-2. Rain-fed Paddy Field Coverage (%) Corresponds to the Number of Samples

No.	Sub-district	Area Extent Ratio (Rain-fed Paddy Field / Sub-District)	70 %	95 %	class	Number of Sample 70%	Number of Sample 95
1	PURWOSARI	13.20	0	0	0	0	0
2	GIRISUBO	18.44	0	0		0	0
3	SAPTO SARI	20.42	0	0		0	0
4	TEPUS	23.55	0	0		0	0
5	TANJUNGSARI	24.33	0	0		0	0
6	RONGKOP	25.43	0	0		0	0
7	GEDANG SARI	8.04	4	0	1	4	0
8	PONJONG	9.42	14	0		14	0
9	NGLIPAR	9.91	6	0		6	0
10	PANGGANG	11.83	1	0	2	1	0
11	SEMANU	12.93	1	0		1	0
12	PATUK	13.96	5	0		3	0
13	KARANGMOJO	21.58	34	4		0	2
14	PALIYAN	23.22	25	5	3	0	2
15	PLAYEN	23.62	52	9		0	3
16	NGAWEN	28.28	28	4		0	2
17	SEMIN	37.93	66	7		0	2
18	WONOSARI	41.10	84	38		0	10
SUM		367.18	320	67		29	21

4.2.4 Analysis

The whole analysis phase was done from indices-profiling at the 50 selected sample locations on the Paddy Growing Period. The paddy growing period is the phase from rain-fed paddy establishment until flowering. This phase takes about 60 – 100 days for the paddy to reach the maximum value of NDVI.

The overall unit analysis on indices and paddy productivity was in administrative sub-districts, over a 14-years period (2000 – 2014). Provided below, the steps for analysis phase were:

4.2.4.1 Indices' Values Extraction

The filtered indices profiles were extracted within a "Paddy Growing Season" for the 1st and 2nd planting. This was a phenology extraction to derive the seasonal parameters as previously mentioned in section 2.5.2 (Jönsson & Eklundh, 2002). The seasonal graphs values were extracted to identify:

- The starting period after transplantation (10% of the distance between the base-value "d" with the maximum-value "f") to indicate a lag occurrence in planting season
- The middle season value that indicates the end period of vegetative phase (maximum or peak value of NDVI)
- The Length of Cycle (LOC) that is the distance between the start-end of paddy growing season to identify the length of growing season
- The amplitude that shows the difference between the maximum-minimum values of indices. Therefore showing the variation of temporal indices values in years
- The green-up rate or staging-up speed that expresses the increasing rate of paddy growing phase (from paddy emergence or paddy establishment). It is expressed by the ratio between the amplitude and the time period from start to middle season.

4.2.4.2 Normal Behavior Evaluation

This was the calculation of the extracted-values from indices profiles, to generate the “normal behaviour” within a Paddy Growing Season (PGS). The normal behaviour analysis was interpreted from the rendition of the indices’ parameters. It was calculated by taking into account the dynamic behaviour from the mean values of previous years, within the same season PGS, with formula:

$$Normal\ Condition = Mean\ Values\ of\ Previous\ Years\ at\ the\ same\ season$$

4.2.4.3 The identification of seasonal anomaly

Indices anomaly was computed by The Standardized (Z-score) Anomaly. It took into account the standard deviation of indices’ variability during a PGS over years. The anomalies are ones that experienced a deviation from the “normal behavior” reference values. The formula was:

$$\text{Standardized (Z} - \text{score)} = \frac{(Current\ Value - Average\ Value)}{Standard\ Deviation\ of\ Previous\ Years}$$

4.2.4.4 Drought Indication Analysis

This phase examined the identified agricultural drought from:

- Five parameters of seasonal graph (start-end period, LOC, mean values, amplitude, and green-up rate)
- The normal behavior and anomaly values of the indices and rain-fed paddy productivity over years,
- Agricultural drought indication of: severity, duration, and frequencies.
  - Severity: change detection on the seasonal standardized (z-score) anomaly values within PGS.
  - Duration: Ratio of dry spells length (elongated dry period) within PGS; where the anomaly indices occurred.
  - Frequencies: Ratio between the percentages of risk years (occurrence) over data period

- The Green-Up Rate Values of the Indices

- The anomaly location for the identified agricultural-drought

4.2.4.5 Comparative Assessment of indices with rain-fed paddy productivity

This was done by using parametric statistic of significance correlation, to examine how strong the relationship of the independent variables (NDVI and NDDI) to the paddy productivity. The comparative assessment was done from the bivariate correlation of “Pearson Product Moment” to compute the correlation coefficient between variables (NDVI with rain-fed productivity, and NDDI with ran-fed productivity).

4.2.4.6 Table Calculation Display

Some tables were generated as the output with information of: (1) the “seasonal anomaly” values to answer the anomaly years of drought occurrences; (2) location map of the rain-fed paddy field that experienced the “anomaly years” to indicate the paddy field location that may have experienced drought; (3) the anomaly values of paddy productivity and indices anomaly values, by sub-district in 14 years; (4) correlation-statistic calculation between variables (indices and rain-fed productivity) over years

4.2.5 Fieldwork Verification

Fieldwork was done to verify the NDVI and the NDDI anomaly values as well as to do in-depth interview with local farmer regarding the historical drought occurrences, as well as its paddy crop productivity. See Annex 9 for the interview sheet.

4.3 Tools and Software

Tools that will be used: ER Mapper, ERDAS and ENVI Classic for MOD09A1 and Landsat 8 processing, ArcGIS 10 for vector data process and map layout.

5. RESULT AND DISCUSSION

5.1 RESULT

The pre-analysis phase was done to process the hyper-temporal images of MODIS TERRA “MOD09A1.” The analysis was started after the images had been processed by several steps as previously mentioned in section 4.2.2, i.e.:

- MOD09A1 images stacking into 658 layers, for a 14-years time-series
- Indices calculation of NDVI and NDWI
- Hyper-temporal images smoothing using TIMESAT (NRS)
- Index calculation of NDDI
- Location sampling of the feasible rain-fed paddy field

The analysis phase was done at the indices profiles (NDVI and NDDI curves) for the particular season of “Paddy Growing Period”. The indices profiles were generated from selecting the MOD09A1 pixel samples that containing the feasible locations of rain-fed paddy field. The unit analysis is in the administrative sub-districts, over a 14-years period (2000 – 2014).

5.1.1 Selected Samples for Indices Profile Analysis

The hyper-temporal profile was generated by selecting one pixel that represents a dynamic performance of the 658 stacked time-series images. The sampling technique for pixel-based indices profiling was described in the section 4.2.3. Figure 5-1 illustrates the 50 selected samples locations for indices profiling.

Location Sampling was done mainly due to the rain-fed paddy field area that was relatively small corresponds to the MOD09A1 pixel size. This brought the analysis to be more on pixel-based level rather than class-based level. Pixel-based analysis was to maximize the sampling selection that represents the dynamic characteristic, majorly from the rain-fed paddy field. While class-based in the other hand may mix-up the information of greenness performance from several pixel values that may not be from majorly rain-fed paddy field.

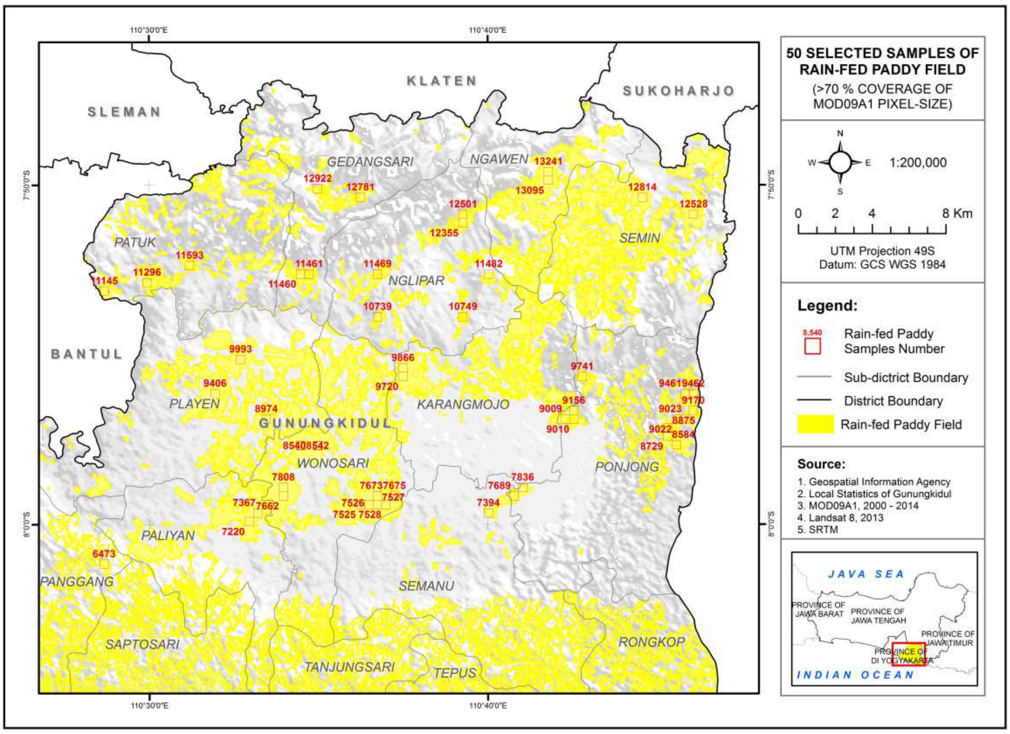


Figure 5-1 Map of rain-fed paddy field area and the 50 sample locations in District of Gunungkidul, Province Yogyakarta Special Region

Figure 5-1 illustrates how the sample locations were selected only in 12 sub-districts out of 18 sub-districts in District of Gunungkidul. The six sub-districts that were not feasible to be analyzed are located at the karstic area in the Southern part of Gunungkidul District, i.e. Purwosari, Saptosari, Tanjungsari, Tepus, Girisubo, and Rongkop. These sub-districts have the area extent of rain-fed paddy field that < 70% coverage, corresponds to the one MOD09A1 pixel size.

Figure 4-3 already showed the ratio of area-extent for rain-fed paddy field by its sub-districts. This ratio was used as a base for selecting the more realistic amount of samples (since the ideal samples were 320 locations for the 70% rain-fed coverage) by using weighted-calculation. The wider the area-extent of rain-fed paddy field in one sub-district, the more samples were selected on that particular sub-district.

By these challenging conditions, the 50 feasible sample-locations were selected for the further indices profiles analysis. See Annex 1 that inscribes the 50 sample locations with ≥ 70% coverage of rain-fed paddy correspond to one MOD09A1 pixel-size; and also Annex 2 that illustrates the landcover overview for the 50 samples, taken from Google Earth.

5.1.2 Indices Profile Parameters within a Paddy Growing Season, Year of 2000 – 2004

The analysis of indices profile was on the "rain-fed paddy growing season" in District of Gunungkidul, for a 14-years period (2000 – 2014). Annex 3 shows the seasonal mean values of NDVI (green dots) and NDDI (red dots) from 50 sample locations, within a paddy growing season, year 2000 – 2014. The x-axis shows the annual paddy growing season (seedling to flowering phase), while the y-ordinate shows the mean values of NDVI and NDDI of 50 samples. Generally, the graph shows the dynamic patterns on the paddy growing season; that as the greenness performance from NDVI mean values are increasing, the NDDI mean values are decreasing.

The graph from Annex 3 also shows that the rain-fed paddy growing seasons were generally started on the 2nd period of October until the 2nd period of November (for the 1st planting), and on the 2nd period of February until the 2nd period of March (for the 2nd planting). This is related to the rainy season in District of Gunungkidul that usually happens in October – April (see Figure 3-5).

Related to the parameters of the indices profile, the examination on the four parameters (FAO, 2011a) was done to identify the agricultural drought in District of Gunungkidul, i.e.: (1) start-end period of the paddy growing season, (2) day length of the paddy growing season, (3) mean values of indices during a paddy growing season, (4) values of minimum, maximum, and amplitude; and (5) green-up rate or staging-up speed of paddy growing phase.

5.1.2.1 Start-End Period of the Paddy Growing Season

In District of Gunungkidul, the starting period of paddy transplantation usually happens in the 2^{nd} period of October until the 2^{nd} period of November (for the 1^{st} planting) and on the 2^{nd} period of February until the 2^{nd} period of March (for the 2^{nd} planting). Annex 3 displays the start-end period of paddy growing seasons throughout years. However, the onset of paddy growing season was found late in several years (see Figure 5-2, extracted from Annex 3).

Figure 5-2 illustrates the mean values of NDVI (green dots) and NDDI (red dots) that experienced delay within the 1^{st} paddy growing season (top), as well as the 2^{nd} paddy growing season (bottom). The x-axis expresses the growing season, while the y-ordinate expresses the mean values of NDVI and NDDI.

Figure 5.2 shows several years when the paddy growing season was starting late. It happened in the years of 2005, 2006, 2007, 2011, and 2013. This condition was firstly brought by the delay of the 1^{st} planting season in late 2005; that then shortened the next paddy growing season (see Figure 5-3).

In those years, the greenness performances for the 1^{st} panting were started increasing in the 3^{rd} period of November – 2^{nd} period of December. While for the 2^{nd} growing season, the greenness performances were started increasing in the 3^{rd} period of March – 2^{nd} period of April. These lag was affected by the delay in the 1^{st} growing season on the respective years (see Figure 5-2).

Related to these delay conditions, dry spell incidents might had happened related to rainfalls condition. Dry spell is the period when dry days are abnormally longer; yet the effect is not as severe as in drought that could destroy the agricultural crop (Barron et al., 2003). Here, in the 1^{st} paddy growing season, the worst delay happened in 2006 (delayed for ± 49 days from normal condition) and for the 2^{nd} paddy growing season, the worst delay happened in 2007 (delayed for ± 33 days from normal condition).

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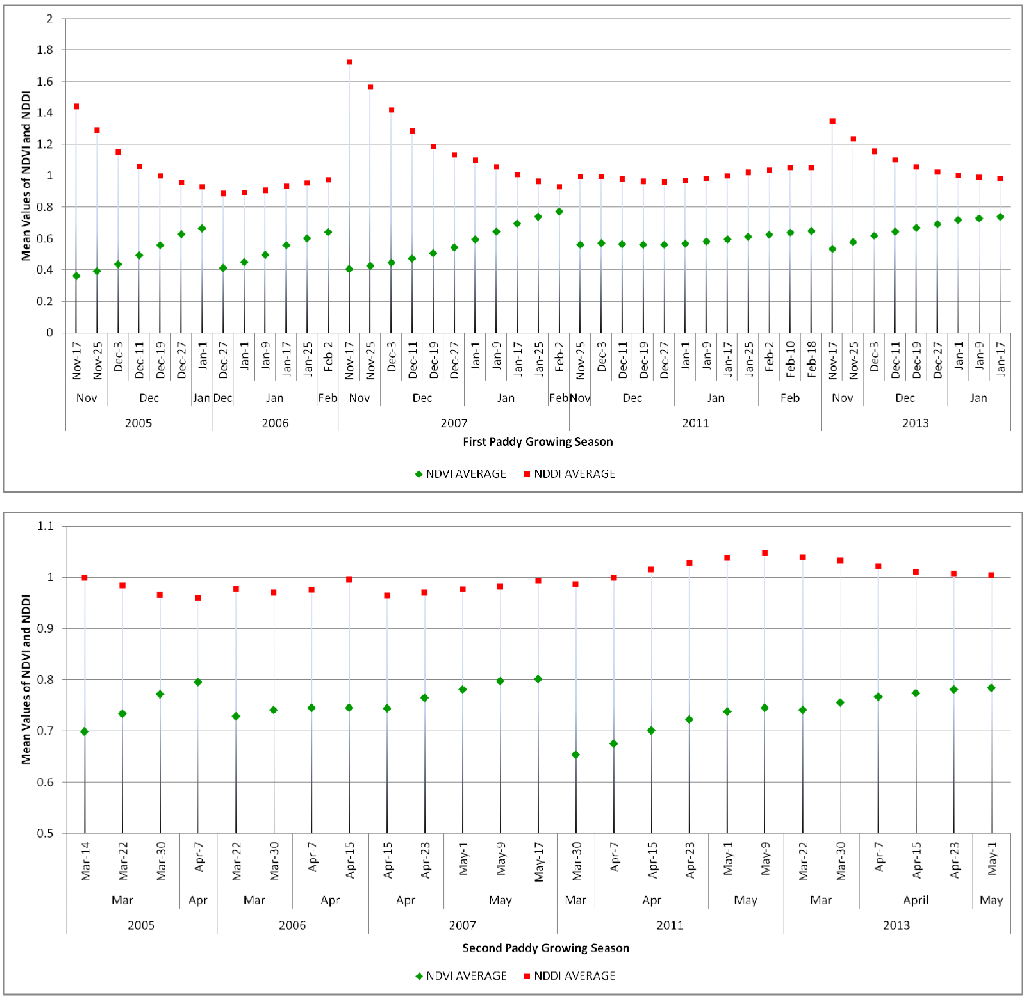


Figure 5-2 Mean Values of NDVI (green dots) and NDDI (red dots) within the 1st Paddy Growing Season (top) and the 2nd Paddy Growing Season (bottom) that experienced a lag in the onset of paddy growing season.

5.1.2.2 Day Length of the Rain-fed Paddy Growing Season

Generally, it takes about 40 – 60 days after the transplantation for the rain-fed paddy to reach its maximum greenness performance. This condition may vary with another area, corresponds to the physical characteristic and the difference in farming practice.

Figure 5-3 shows the total length of paddy growing season (seedling to flowering phase) on the 1st and 2nd Planting over years. The x-axis expresses the years, while the y-ordinate expresses the length of season (in days). The longest cycle were happened in 2010 – 2011 (130 days), while the shortest was in 2006 (66 days). The blue curve shows the average values from Length of Cycle (LOC).

It shows that year of 2005, 2006, and 2012 experienced a relative shorter LOC (37, 33, and 45 days in average or 74, 66, and 90 days in total LOC respectively).

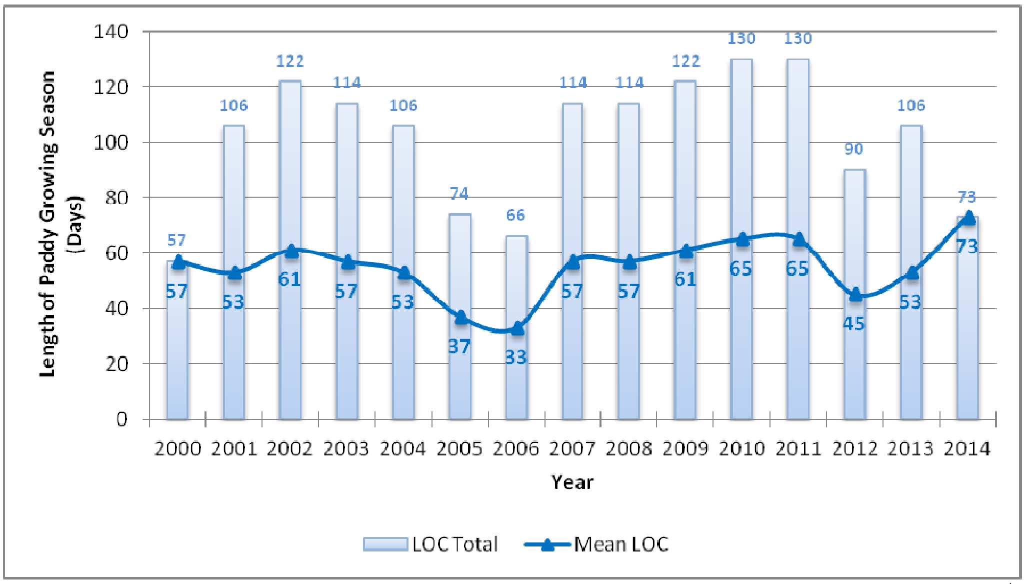


Figure 5-3 Total and Mean Length of Paddy Growing Season (days) on the 1st and 2nd Planting, District of Gunungkidul, Year of 2000 – 2014

Figure 5.4 illustrates seasonal length of paddy growing season over years and its standard deviation values. The 1st planting are shown in darker green columns, while the 2nd planting are in the brighter green column. Generally, the graph shows that the 2nd planting seasons took a relatively shorter period for paddy to grow.

The graph 5-4 shows that on the 1st planting, the longest paddy growing season happened in 2011 (took ± 89 days for paddy to grow). While the shortest was in 2006 (took ± 41 days). Meanwhile on the 2nd planting, the longest happened in 2000 – 2003 (took ± 57 days for paddy to grow), and the shortest was in 2005 – 2006 (took ± 25 days). The standard deviation (SD) values shown in blue curves show how big the detected change occurred. Higher SD values mean a higher change, either in increasing or decreasing condition.

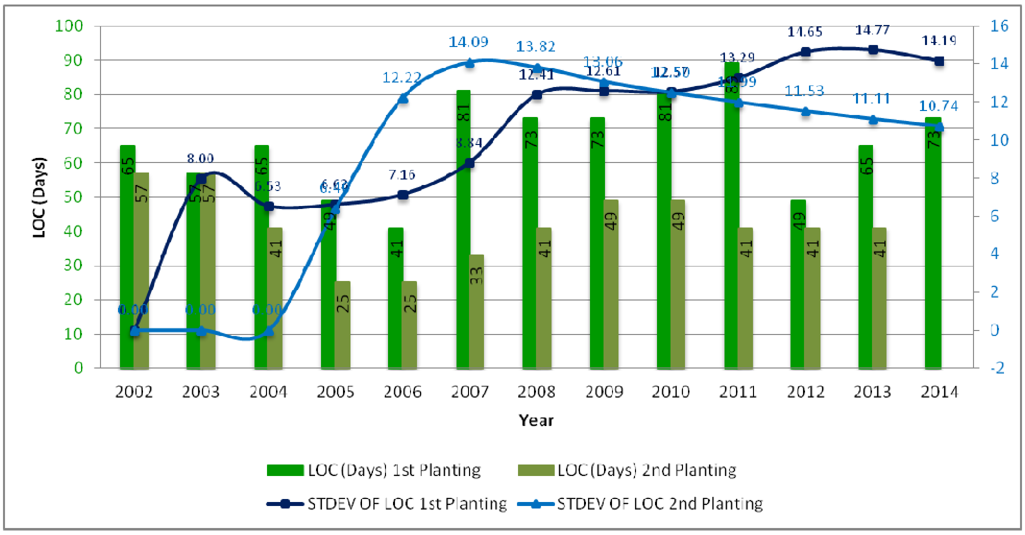


Figure 5-4 Seasonal LOC and Change Detection of Paddy Growing Season on the 1st and 2nd Planting, District of Gunungkidul, Year of 2000 – 2014

All the values described were interpreted as: the 1st planting season happened in the rainy season on the previous year, while the 2nd planting period happened on the exact particular year.

Related to the rainfalls condition, dry periods may shorten the paddy growing phase, while wet periods may lengthen it. Therefore, the shifting in the rainy season on a particular year could affect the length of paddy life cycle as well as the starting time of paddy growing season.

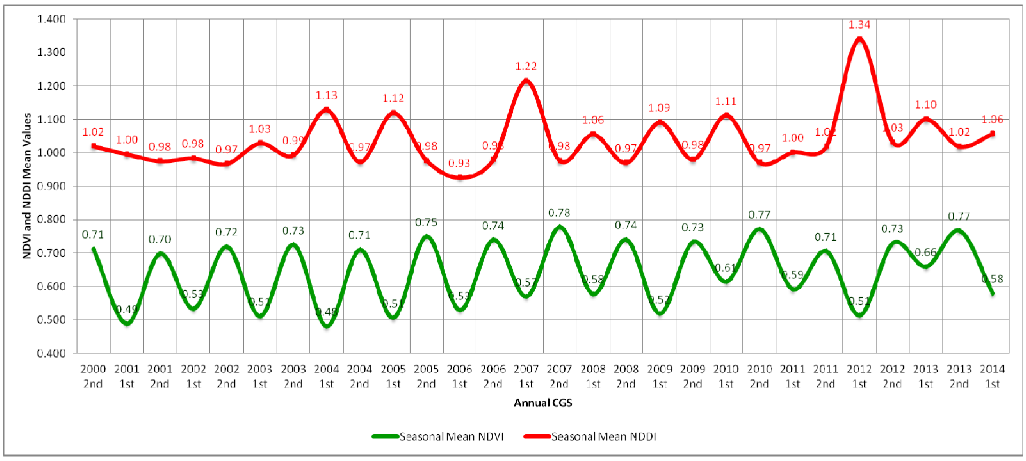
From the Figure of 5-3 and 5-4, the longer growing phase for the 1st planting season in the late of 2010 – 2011 might indicate that there were relatively high rainfalls in the late 2009 – 2010. Meanwhile, the relatively shorter period of 2nd planting season in 2005 – 2006 might have been affected by the shifted in paddy growing season on the 1st planting in respective years.

5.1.2.3 Mean Values of Indices during a PGS throughout Years 2000 – 2014

Figure 5-5 expresses the mean values of NDVI and NDDI within a paddy growing season throughout years. Figure 5.5 (top) illustrates the seasonal mean values of indices. Figure 5.5 (middle and bottom) show the dynamic mean values for NDVI and NDDI in each sub-district. The x-axis expresses the year, while the y-ordinate expresses the indices' mean values.

The NDVI histogram in figure 5-5 (top) generally shows how the seasonal mean values of NDDI were relatively increasing higher in the 1st paddy growing season in 2004, 2005, 2007, and 2012. While from the NDVI histogram, these years show the relatively lower values of NDVI average. The decreasing mean-values of NDVI or the increasing mean-values of NDDI could indicate that there were poor performances of paddy photosynthetic activity in those periods.

Furthermore, the graphs also display several sub-districts that experienced a dynamic performance that was constantly lower or higher than the indices' annual mean values. Figure 5-5 (middle and bottom) show that over years, Sub-districts of Paliyan and Wonosari did not only experience a lower values than the NDVI mean-values (represented in reddish curves), but also experience a higher values than the NDDI mean-values (represented in greenish curves). This spatial specialty could be associated with the physical condition of each sub-district.



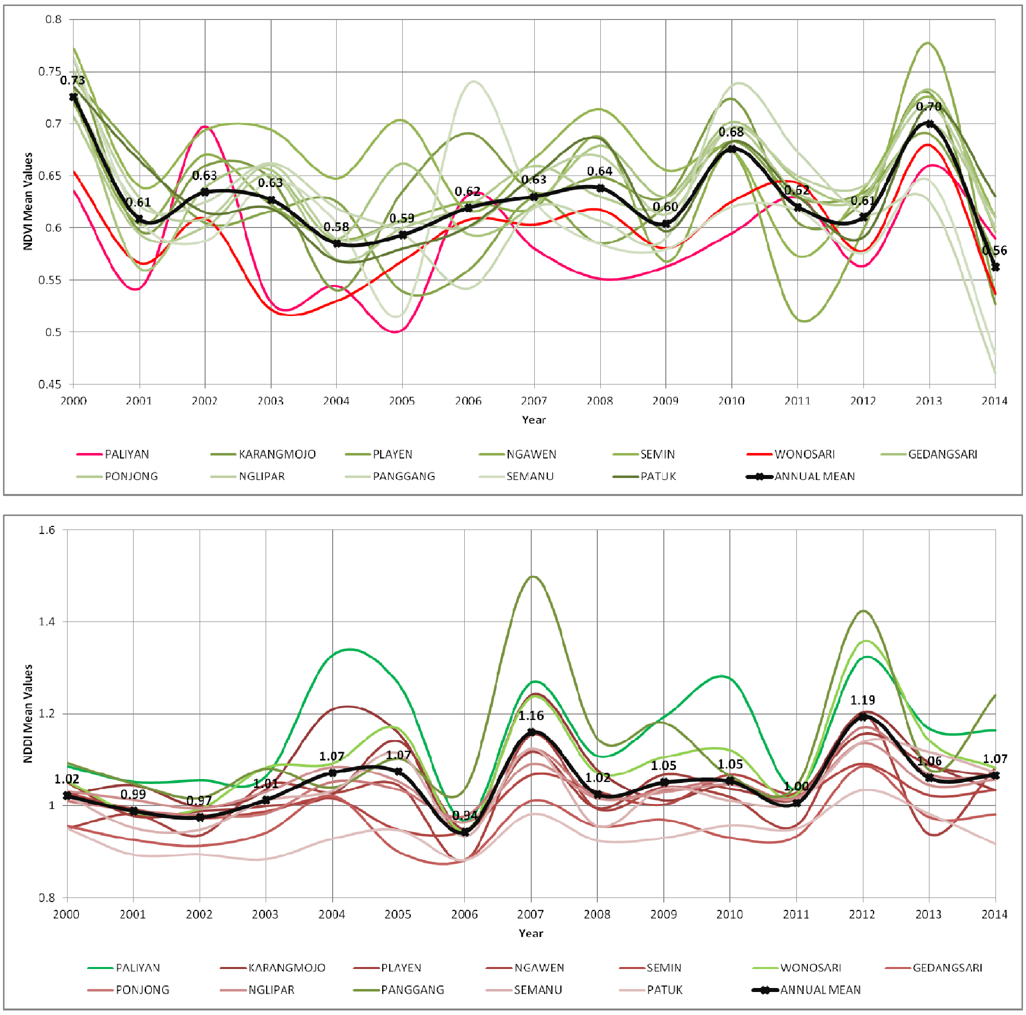


Figure 5-5 Mean Values of NDVI NDDI: Seasonal Values (top), NDVI Mean (middle) and NDDI Mean (bottom) by Sub-districts; within a Paddy Growing Season, Over 14 Years

5.1.2.4 The Minimum, Maximum, and Amplitude of Indices Vslues

The amplitude expresses the range of maximum and minimum values of indices histogram throughout years. It describes the difference values between the maximum (peak) indices with the minimum (base) indices. Therefore, amplitude shows the variation of temporal indices values over years. The lower the amplitude, the lower the difference between maximum and minimum of indices is.

Figure 5-6 displays the extracted values of minimum, maximum and amplitude of NDVI and NDDI over years. The x-axis shows the Paddy Growing Season over 2000 – 2014, while the y-ordinate shows the values of indices. The relatively high variations were found majorly in the 1st planting season. Besides, the graph also illustrates how the variation value of NDDI is higher than NDVI.

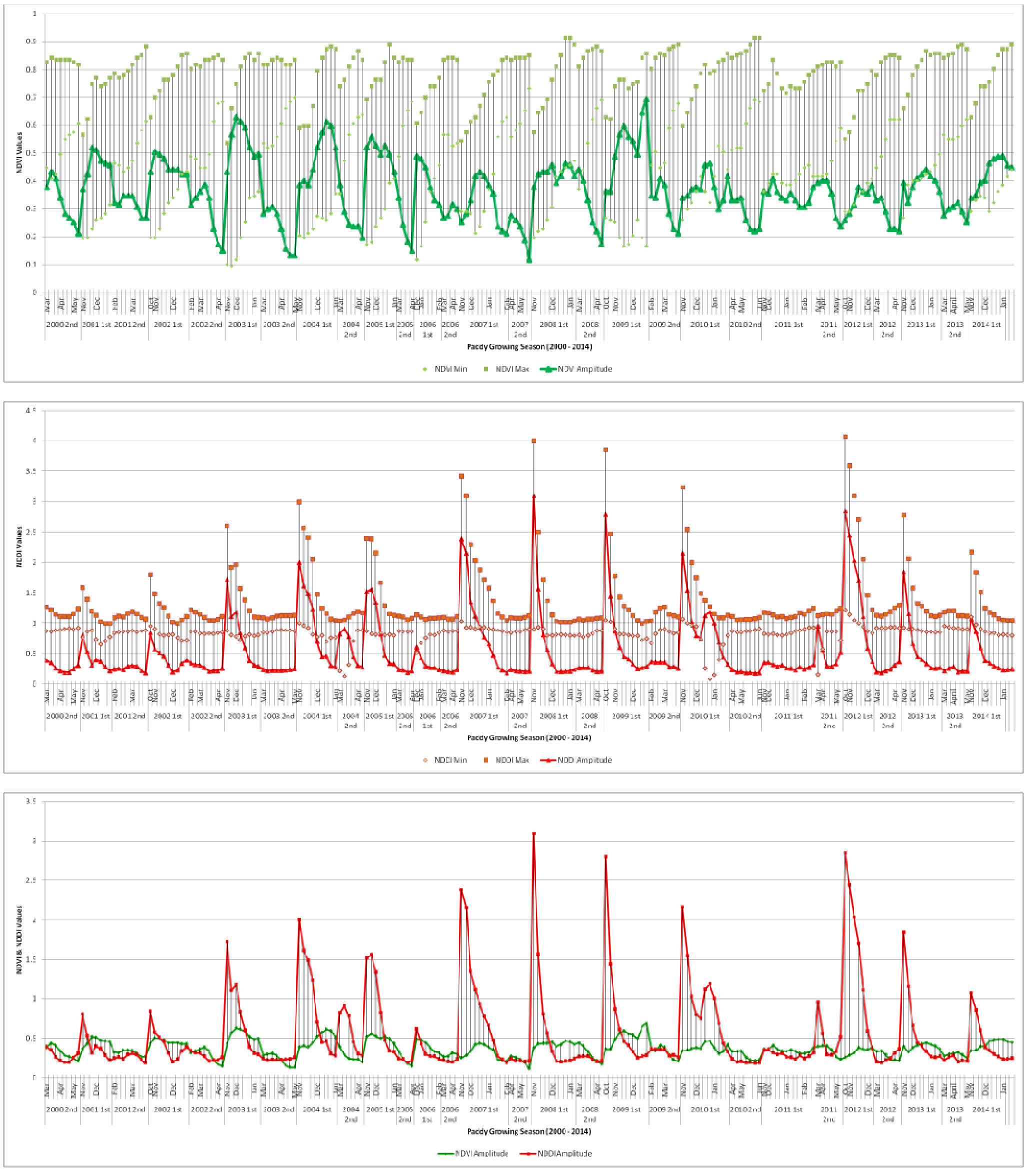


Figure 5-6 the Minimum, Maximum, and Amplitude Values of NDVI (top), NDDI (middle), and the Amplitude Comparison between NDVI and NDDI (bottom), Within a Paddy Growing Season in District of Gunungkidul, Year of 2000 - 2014

From the NDVI curve (Figure 5.6 top) the amplitude ranges between 0.118 – 0.693. The lowest amplitude was found in 2nd planting 2007 (0.118), and highest was in 1st planting in 2009 (0.693). From the NDDI curve (Figure 5.6 middle), the range of amplitude was 0.186 – 3.093. The lowest amplitude was found in 2nd planting 2010 (0.186), and the highest value was in 1st planting of 2008 (3.093).

Figure 5.6 (bottom) shows that in the difference between maximum and minimum of NDDI mean values were higher than NDVI; so does the 1st planting that higher than the 2nd planting. This is related to the paddy growing season that relatively takes shorter period for paddy to grow.

5.1.2.5 The Green-Up Rate Values of the Indices

Green-up rate expresses the staging-up speed or increasing rate from the paddy growing phase (paddy emergence or the paddy establishment). It is the halfway points between the minimum-maximum values. This was expressed by the ratio between the amplitude and the time period from start to middle season.

Figure 5.7 shows the green-up rate of NDVI (top) and NDDI (bottom) within a paddy growing season over 14-years of study. The x-axis shows the year; while the primary y-ordinate shows the growth rate (%) and secondary y-ordinate shows the length of paddy growing season. In NDVI histogram, lower rate values indicate a dry period occurred in that years; while in NDDI histogram, higher rate values indicate a dryer condition. This is related to the condition where dry period may shorten the growing phase, while wet period may lengthen it.

The NDVI histogram shows that the plummeted growth rate occurred in years of 2002, 2007, and 2010. While from the NDDI histogram, the rising growth rate occurred in 2005, 2007, 2010, and 2012.

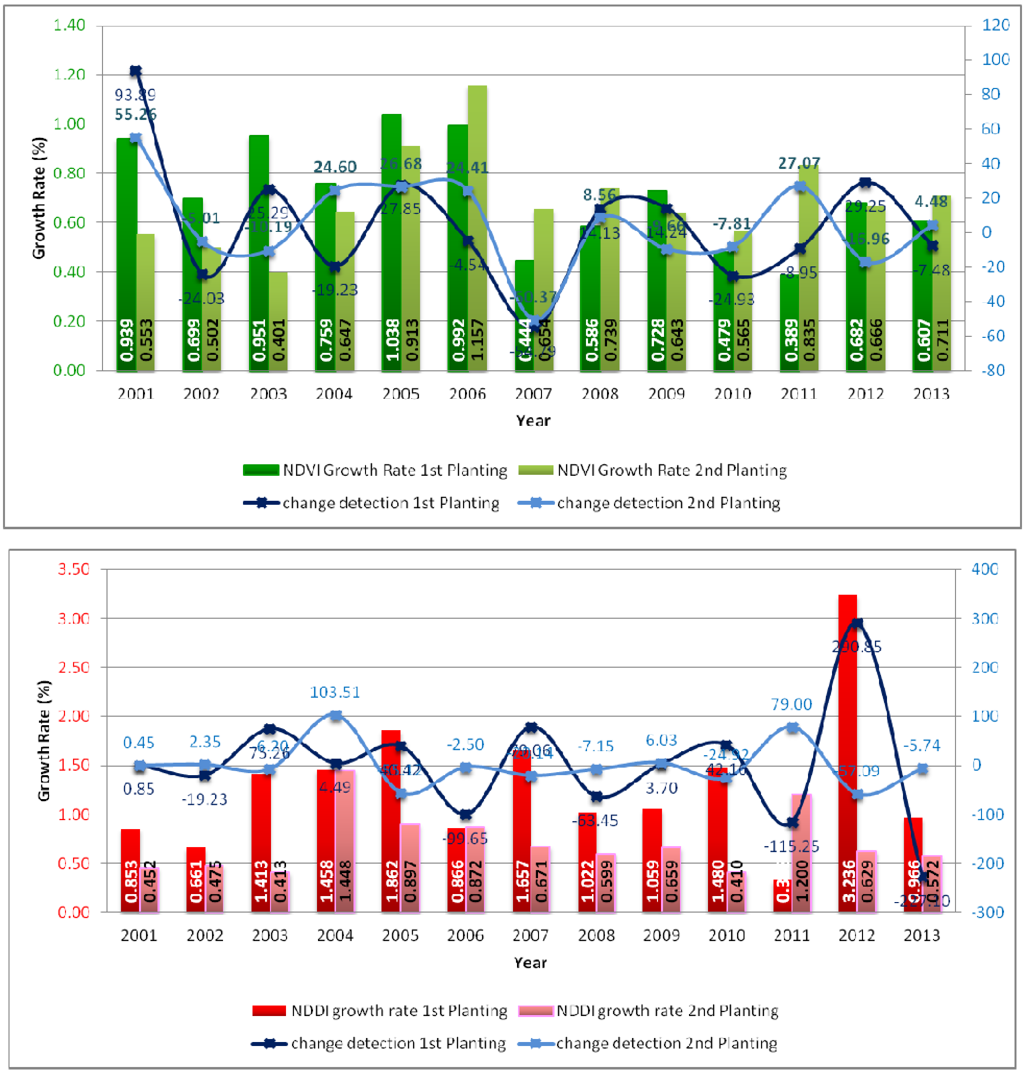


Figure 5-7 the The Green-up rate of NDVI (top), NDDI (bottom), Within a Paddy Growing Season in District of Gunungkidul, Year of 2000 – 2014

5.1.3 Normal Behavior and Anomaly Calculation of the NDVI and NDDI Values on a Paddy Growing Season, Year 2000 – 2014

5.1.3.1 Seasonal Values of Normal Behavior and Anomaly Calculation

The normal behavior was generated from the mean values from the previous years, taken from the sample locations within a paddy growing season. Figure 5-8 illustrates the normal condition and anomaly values of NDVI and NDDI within a Paddy Growing Season over years. The x-axis expresses the year, while the y-ordinate expresses the indices values of normal and anomaly condition. The blue line in both histograms represents the normal condition of both indices within a paddy growing season throughout years.

From the NDVI histogram (figure 5-8 top), the normal behavior was in range of 0.503 – 0.778 over a 14-years period. Meanwhile from the NDDI histogram (figure 5-8 bottom), the normal behavior was in range of 0.967 – 1.085.

Generally, anomaly expresses a deviation at a current year from the normal condition at the same season (FAO, 2011b). It was calculated from the standardized (z-score) to expresses the number of standard deviation from a current year that is deviated from the normal condition.

From the NDVI behavior histogram (figure 5-8 top), the deviated anomaly values from normal behavior happened in 2003 – 2005, 2009, and 2012 (for the 1st planting season); also in 2004, 2008 – 2009, and 2011 – 2012 (for the 2nd planting season). From the NDDI behavior histogram (figure 5-8 bottom), the positive deviation values from normal behavior were in 2003 – 2005, 2007, and 2012 (for the 1st planting season), and in 2011 – 2013 (for the 2nd planting season).

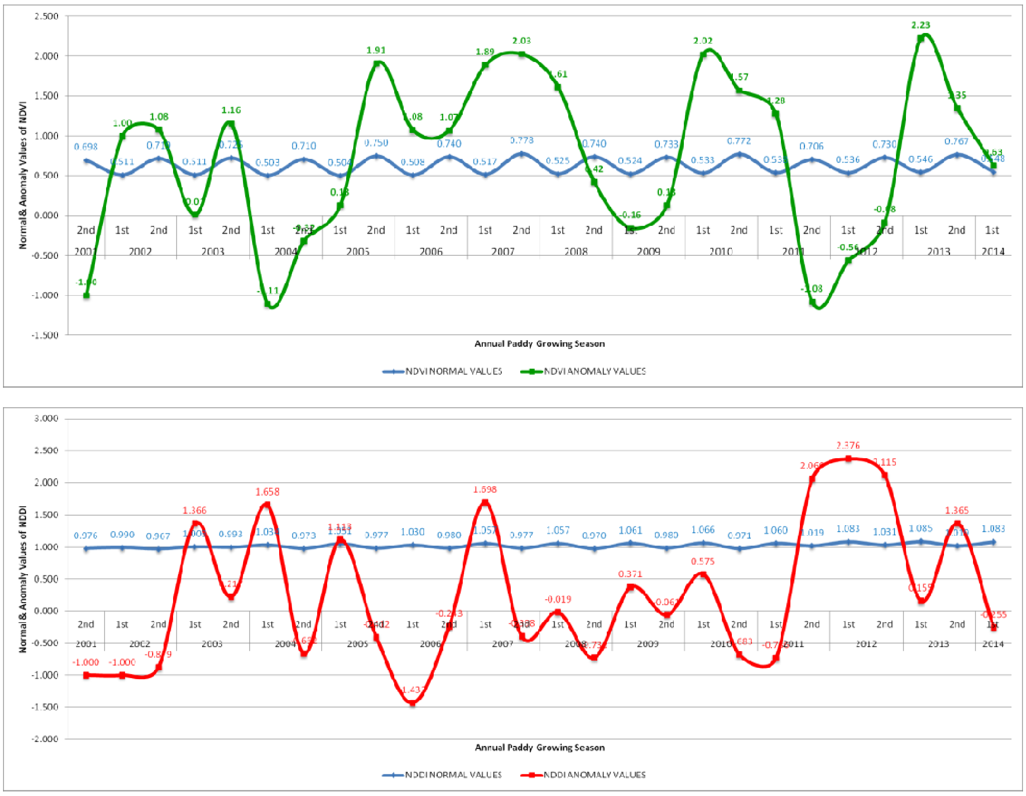


Figure 5-8 the Normal Behavior & Anomaly Values of NDVI (top) and NDDI (bottom) on the Paddy Growing Season by Years in Each Sub-district

5.1.3.2 Anomaly of the NDVI and NDDI by Years, by Sub-districts

Figure 5.9 displays the calculated anomaly of NDVI (top) and NDDI (bottom) by sub-districts over years. The x-axis shows the year, while the y-ordinate shows the standardized (z-score) anomaly values. These graphs generally illustrate how some sub-districts were deviated from its normal behavior throughout years.

From the NDVI anomaly histogram (Figure 5.9 top); sub-districts of Wonosari and Paliyan had the lowest deviation from the normal behavior over years (represented in bluish curves). While from the NDDI anomaly histogram, sub-district of Paliyan, Wonosari, Karangmojo, and Panggang experienced a higher deviation than the other sub-district (represented in bluish curves). The anomaly values of NDVI and NDDI by sub-district over years was provided in Annex 7.

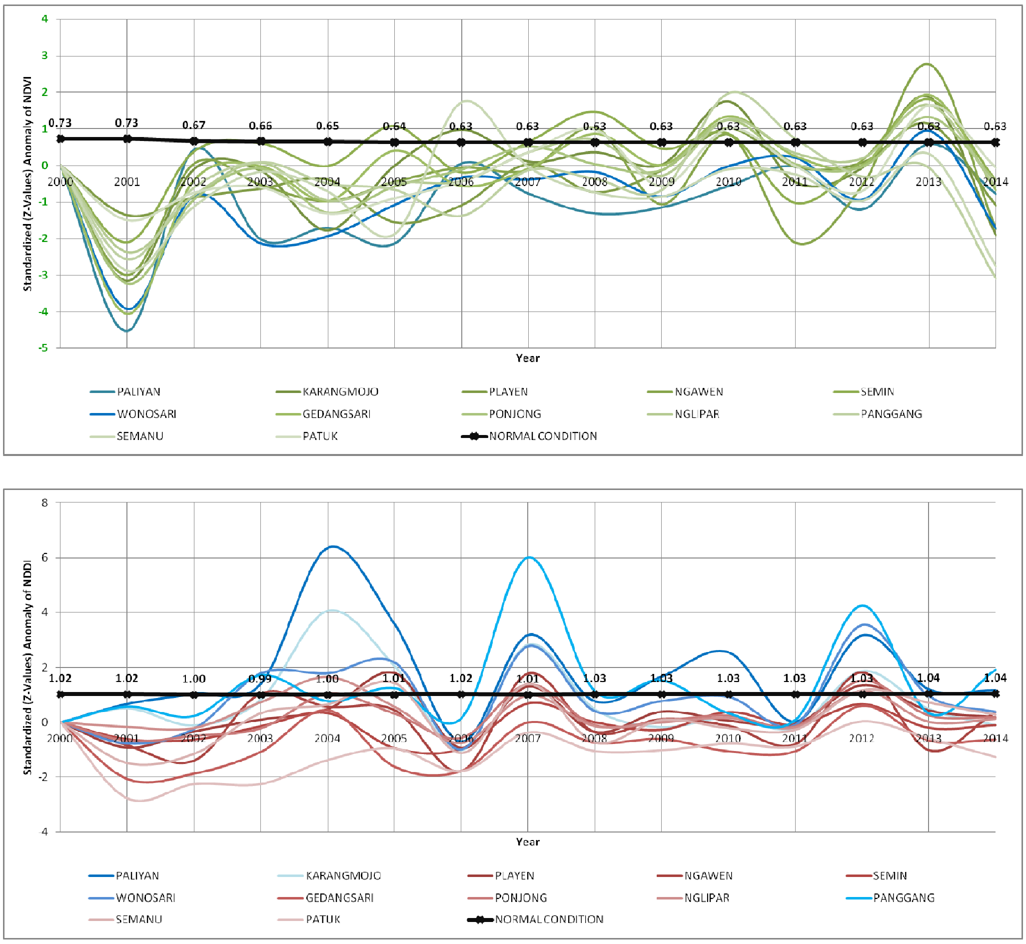


Figure 5-9 the Standardized (z-score) Anomaly Values of NDVI (top) and NDDI (bottom) by Years by Sub-districts

5.1.4 Normal Behavior and Anomaly Values of Paddy Productivity

5.1.4.1 Normal and Anomaly Calculation of the Rain-fed Paddy Productivity

The rain-fed paddy productivity (Qu/Ha) in District of Gunungkidul over years could be seen from Figure 3-9. The graph shows how the rain-fed paddy productivity has an increasing trend over years, especially since 1999. Besides, the graph also shows that within 2000 – 2014, the rain-fed productivity in District of Gunungkidul experienced a slight decline in several years of 2000, 2002, 2005, 2007, 2010, and 2013 (see Figure 3-9). The spatial distribution of rain-fed productivity could be seen from Figure 3-10.

Figure 5-10 shows the normal condition of the rain-fed paddy productivity compared to its standardized (z-score) anomaly values. The x-axis shows the years of study; the primary y-ordinate shows the rain-fed paddy productivity (Qu/Ha); and the secondary y-ordinate shows the anomaly values of rain-fed productivity (dark blue curve) and its change-rate values (blue curve).

The graph shows that the normal behavior of rain-fed productivity has an increasing trend over a 14-years period of study. The range of normal behavior from rain-fed productivity was 26.54 – 33.57 in year of 2000 – 2013. The normal behavior is shown in brown-colored line (see Figure 5-10).

The anomaly values of rain-fed paddy productivity were deviated negatively in years of 2002, 2004 – 2005, 2007, 2009 – 2011, and 2013. The lowest anomaly occurred in 2013 (z-score = 1.51). However, the worst plummeted negative anomaly was in 2007 (z-score = 1.90, dropped -1.71 point from year of 2006) (see Figure 5-10).

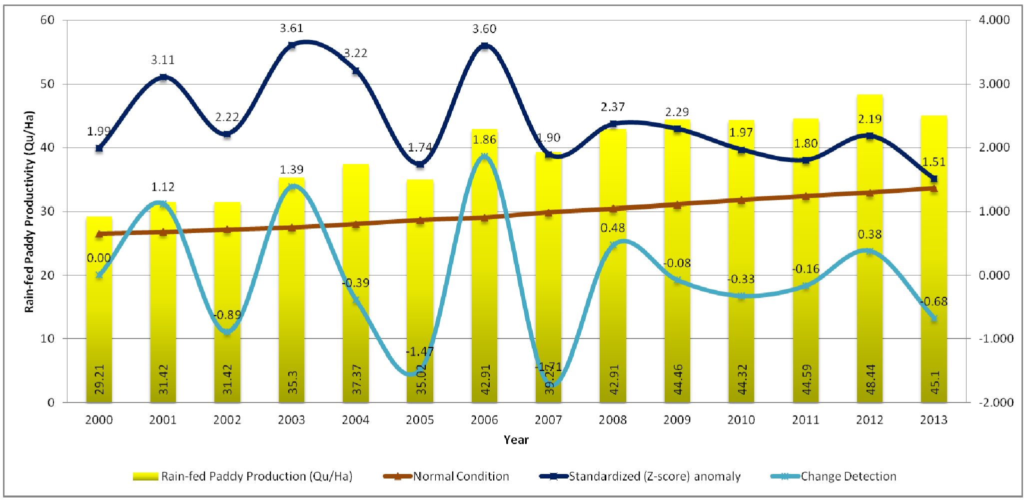


Figure 5-10 Normal Condition and the Standardized (Z-Score) Anomaly of Rain-fed Paddy Productivity in District of Gunungkidul (2000 – 2013)
Source: (BPS, 2013)

5.1.4.2 Anomaly Location of the Rain-fed Paddy Productivity

Figure 5-11 shows the rain-fed paddy productivity average (Qu/Ha) and its rain-fed paddy field area extent (Ha) over years. Spatially, Figure 5-11 shows two sub-districts that relatively have a lower productivity than the other sub-districts over years. These sub-districts are Patuk and Panggang. This is related to the physical condition of those sub-districts. Patuk is a hilly area, located in the Northern part of Gunungkidul District, while Panggang is a karstic area, located in the Southern part of Gunungkidul District. Annex 5 provides the rain-fed productivity data by sub-districts.

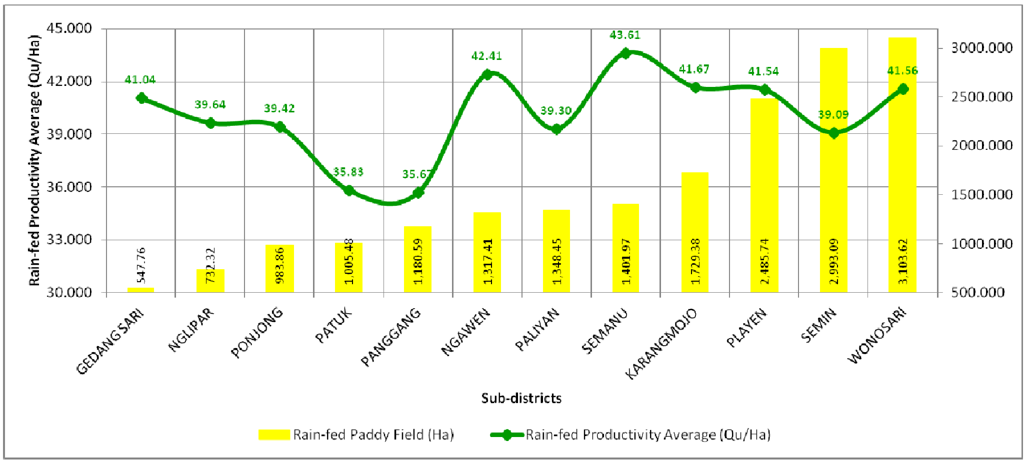


Figure 5-11 Rain-fed Paddy Productivity Average (Qu/Ha) and Its Field Area Extent (Ha), by sub-districts, years 1997 – 2013
Source: (BPS, 2013)

Figure 5-12 shows the standardized (z-score) anomaly of rain-fed paddy productivity by years, by sub-districts. The colored-columns show the anomaly occurrences by sub-districts over years; while the blue curve shows the rain-fed productivity (Qu/Ha) over years.

Figure 5-12 shows that the negative anomaly values of rain-fed productivity were mostly occurred in 2001 – 2002 and 2005. These negative anomalies were related to the productivity average (shown in blue line) that were stagnant in 2001 – 2002 and declined in 2005. The anomaly values of rain-fed paddy productivity by sub-districts over years was provided in Annex 8

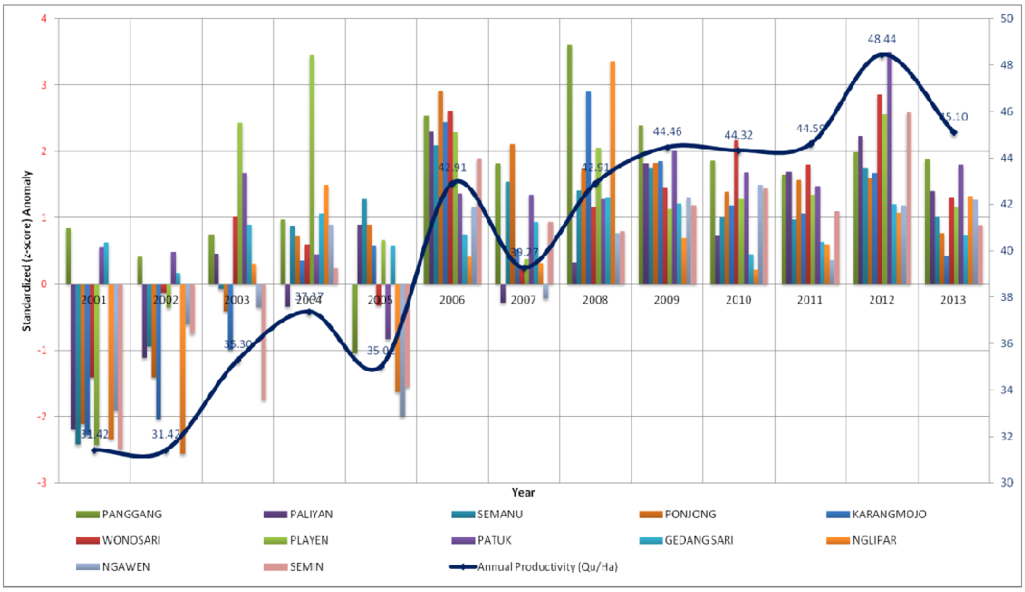


Figure 5-12 The Standardized (z-score) Anomaly of Rain-fed Paddy Productivity by Years, by Sub-districts

5.1.5 The Agricultural Drought Indication

The Agricultural Drought Indication in District of Gunungkidul was done by evaluating the indices profile parameters and its anomaly occurrences to get the overview of severity (magnitude) and duration of Agricultural Drought.

5.1.5.1 Severity or Magnitude of Agricultural Drought in District of Gunungkidul

The severity or magnitude of agricultural drought was analyzed from the change detection of standardized (z-score) values within the similar periods of paddy growing season. Zero values mean no detection. The higher calculated values, the higher the change was. The negative values indicate that the second images were decreasing than the previous period.

Figure 5.13 shows the change rate of NDVI and NDDI z-score values. The x-axis shows the year of paddy growing season, while the y-ordinate shows the change-rate detection of indices' z-score (%). This graph shows that the relatively high change-rate in anomaly happened in NDDI histogram in years of 2003 (2.37), 2007 (3.13), 2011 (2.75), and 2012 (3.11). While from the NDVI histogram, the relatively high change-rate in anomaly occurred in 2001, 2003 – 2004, 2006, 2008 – 2009, and 2011 – 2012.

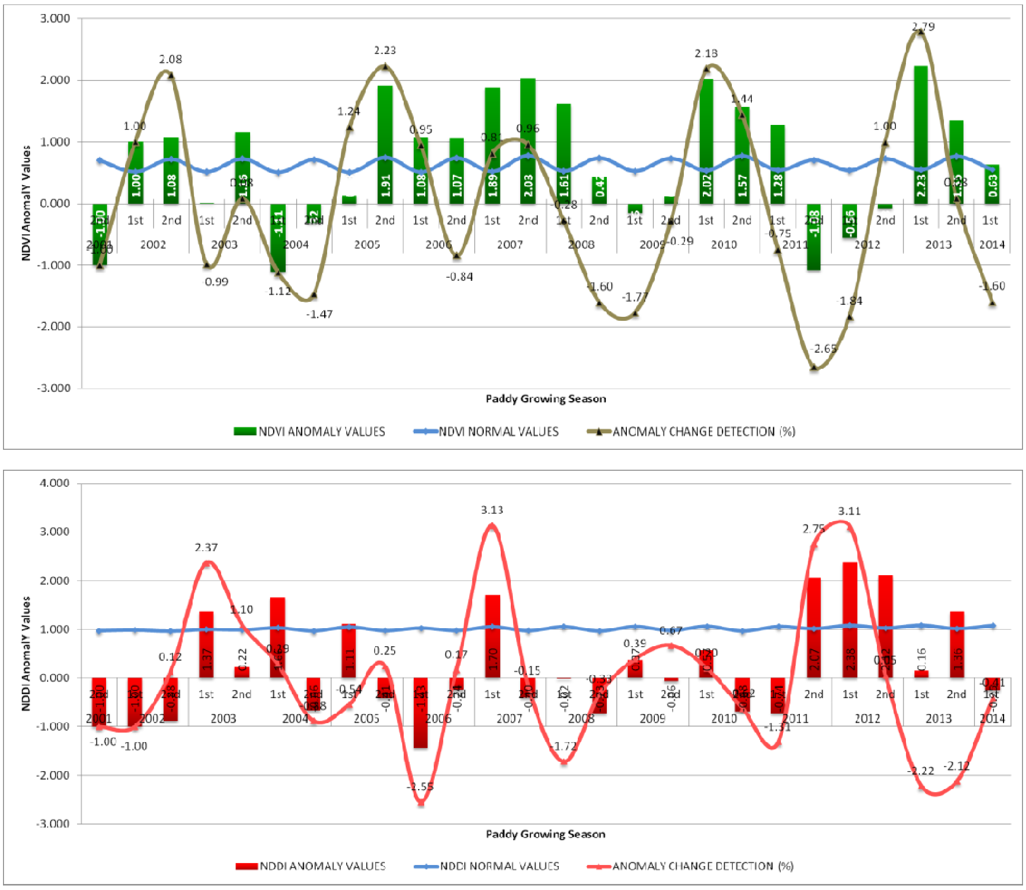


Figure 5-13 the Standardized (z-score) Anomaly Calculation of NDVI (top) and NDDI (bottom) and Its Change Detection, by Years

5.1.5.2 Duration of Agricultural Drought in District of Gunungkidul

The duration of agricultural drought was assessed from the ratio of length of dry spells (elongated dry months) within a paddy growing season. The lag length was indicated from the delayed-onset in paddy growing season. Then, the duration was generated from the period length; where the anomaly indices occurred.

The pie figure 5-14 shows the dryness duration (%) of elongated dryness period (%) within anomaly years. It expressed in lag percentage within PGS where anomaly occurred; in 2003 (42 %), 2005 (42 %), 2007 (42 %), 2011 (51 %), and 2012 (45%).

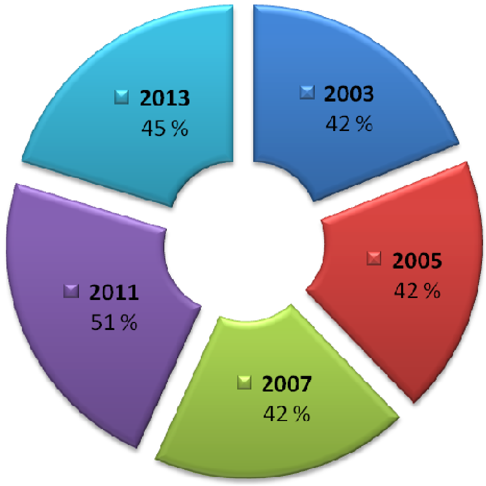


Figure 5-14 Duration of Elongated Dryness Period (%) within Anomaly Years

5.1.5.3 Frequency of Agricultural Drought in District of Gunungkidul

Frequency of Agricultural Drought was calculated from the ratio between the percentages of risk years (occurrence) by the entire data period. It was found that throughout 14-years of study, the anomaly years that correspond to the rain-fed declined-productivity were happened in 7 years of: 2003 – 2005, 2007, 2009, and 2011 – 2012. Therefore, the risk frequency of dryness period in District of Gunungkidul within 2000 – 2014 was 50 %.

5.1.5.4 Anomaly-Maps Representation in District of Gunungkidul

Anomaly map illustrates the anomaly occurrence at a specific time in a particular location. Annex 4 displays the time-series images showing the greenness performance from paddy growing season, during the anomaly occurrence in year of 2003, 2005, 2007, 2009, and 2011 – 2012.

Vegetation activity of the rain-fed paddy that was in poor was represented from the low NDVI values (light green color range) and high NDDI value (reddish color range). This color area might indicate dryness occurrence.

5.1.6 Comparative Assessment

Statistical computation was done to calculate the correlation coefficient values by using Pearson Product Moment. The comparative assessment was done between the independent variables of NDVI and NDDI (mean, normal behavior, and anomaly values) with the dependant variable of rain-fed paddy productivity.

Table 5-1 provides the calculated values for: indices values (annual mean, normal behavior and anomaly values) correspond to the rain-fed productivity in 2000 – 2014. While table 5-3 shows the result of comparative assessment

Based on the comparative assessment from Table 5-3, the NDDI gave a relatively stronger correlation to paddy productivity than the NDVI gave. This comparison was calculated in terms of annual mean values, standardized anomaly values, and normal behavior. Here, NDDI gave a stronger correlation to paddy productivity than the NDVI gave. NDDI was correlated higher with productivity in terms of annual mean indices values (38.19 %), normal behavior (82.60 %), and standardized anomaly values (-0.2628).

Table 5-1. Values of Indices, Anomaly, & Normal Behavior Over Years

YEAR	INDICES MEAN VALUES		STD (Z-SCORE) ANOMALY		NORMAL BEHAVIOUR	
	NDVI	NDDI	NDVI	NDDI	NDVI	NDDI
2001	0.608386	0.9882	-2.88865	-0.71128	0.725656	1.021171
2002	0.634399	0.97424	-0.46192	-0.61774	0.667021	1.004686
2003	0.626942	1.012152	-0.46245	0.355935	0.656147	0.994537
2004	0.584745	1.071224	-1.04317	1.396628	0.648846	0.998941
2005	0.593215	1.072826	-0.68401	0.843999	0.636026	1.013398
2006	0.619237	0.942073	-0.1521	-1.01881	0.62889	1.023302
2007	0.630042	1.159448	0.040896	1.829368	0.627511	1.011698
2008	0.638274	1.024224	0.178641	-0.05861	0.627828	1.030167
2009	0.604163	1.050246	-0.43165	0.211754	0.628988	1.029506
2010	0.676001	1.052817	0.887831	0.221114	0.626506	1.03158
2011	0.620065	1.004564	-0.19408	-0.30432	0.631005	1.033511
2012	0.610088	1.193194	-0.36182	1.762469	0.630094	1.031099
2013	0.700196	1.060034	1.329866	0.159576	0.628555	1.043568

Table 5-2. Rain-fed Paddy Productivity, Anomaly Values, & Normal Behavior, Year 2000 – 2014

YEAR	RAIN-FED PADDY PRODUCTIVITY (Qu/Ha)	RAIN-FED PADDY PRODUCTIVITY ANOMALY	RAIN-FED PADDY PRODUCTIVITY NORMAL BEHAVIOUR
2001	31.42	3.110416	26.78091
2002	31.42	2.21584	27.1675
2003	35.3	3.606567	27.49462
2004	37.37	3.216854	28.05214
2005	35.02	1.744677	28.67333
2006	42.91	3.601653	29.07
2007	39.27	1.89615	29.88412
2008	42.91	2.373174	30.40556
2009	44.46	2.294132	31.06368
2010	44.32	1.967653	31.7335
2011	44.59	1.8042	32.33286
2012	48.44	2.186573	32.89
2013	45.1	1.508871	33.56609

Table 5-3 the Comparative Assessment Result Using Pearson Product Moment

PRODUCTIVITY VS INDICES		STD (Z-SCORE) ANOMALY		NORMAL BEHAVIOUR	
Productivity VS Mean NDVI	Productivity VS Mean NDDI	Anomaly Productivity VS NDVI	Anomaly Productivity VS NDDI	Normal Productivity VS NDVI	Normal Productivity VS NDDI
0.3251	0.381932	-0.50851	-0.26279	-0.68549	0.825955

5.2 DISCUSSION

5.2.1 Agricultural Drought Identification in District of Gunungkidul Using Satellite-based Indices

The analysis was done by evaluating the four parameters of indices profile, as well as correlating it with the rain-fed productivity, District of Gunungkidul was found not to experience a severe agricultural drought. The productivity had not experienced a devastating condition affected by the several anomalies of vegetation greenness performance found in anomaly years of: 2003 – 2005, 2007, 2009, and 2011 – 2012. Though, this deviated condition from the normal behavior was corresponded to the decreasing productivity of rain-fed paddy field.

This research showed some area that experienced poor vegetation performance in anomaly years were in Sub-districts of Paliyan, Wonosari, and Panggang. These sub-districts commonly experienced the greenness performance that was lower than the NDVI normal condition and higher than the NDDI normal condition.

However, from the annual mean values of NDVI and NDDI anomaly; generally all sub-districts experienced a slight decline from the indices' normal behavior. Yet, those three sub-districts previously mentioned were experiencing a higher deviation than the other sub-districts.

Moreover, this research found that from the comparison analysis, NDDI gave a stronger correlation to paddy productivity than the NDVI gave. NDDI was correlated higher with productivity in terms of annual mean indices values (38.19 %), normal behavior (82.60 %), and standardized anomaly values (-0.2628).

5.2.2 Identified Dryness Related to the Physical Condition of District of Gunungkidul

The evaluated anomaly of rain-fed paddy behavior within a paddy growing season could be associated with the physical condition of Gunungkidul District, e.g. with the rainfalls, soil, morphology, and the agricultural practices.

- Annual Rainfall Condition (mm) and the amount of wet months (days)

  Figure 5-15 shows the general overview of annual rainfall in mm (top) and annual amount of rain days (bottom). It shows that while in 2005, 2007, and 2012; the vegetation performance was behaved poorly though the rainfall amount in particular time was reportedly high. In 2010 the annual rainfall was 2,295.69 mm and in 2005 was 2,145.00 mm

  However, from the annual amount of rain days; year of 2005, 2007, and 2012 were experienced a moderate wet months that experienced a slight declination.

Figure 5-15 Annual Mean Rainfalls (top) & Mean Rain days (bottom) Compared to Annual Mean of Indices Values
Source: (BPS, 2002, 2006, 2009, 2013b)

- Morphology

Geomorphologic condition in District of Gunungkidul also has an important role corresponds to the sampling location of rain-fed paddy field. The southern zone (Zone of Gunung Seribu or Zuider gebergton) is a karst zone with conical limestone type. About 11 sub-districts are located at this area (Saptosari, Paliyan, Girisubo, Tanjungsari, Tepus, Rongkop, Purwosari, Panggang, Souhtern Ponjong, and Souhtern Semanu) (Local Government of Gunungkidul District, 2014). Besides, the geo-hydrological type is mostly covered by a highly-gap aquifer that has many underground rivers

- Agricultural Practice: the variety changing of rain-fed paddy seeds

  From the agricultural practice, the changing in farming ways could affect the paddy productivity, e.g.: the planting methods (tumpangsari), the irrigation, the farming tools, and the changing in crop variety.

  From the field observation, in year of 2012, there was a mass changing in paddy variety from "Ciherang" to "Situ Bagendit." This condition was reported affecting the decreasing productivity in 2013.

5.2.3 Challenges in Deriving the Indices Values

The indices were generated from spectral observation. This examination has some challenges that would affect the quality of analysis result, e.g.:

- The spatial and temporal resolution from the images corresponds to the area extent of the observed objects. The moderate scale of images or low-temporal resolution may bring challenges to the observation of a relatively small areas or small objects.
- Defining the normal and anomaly behavior is something to take into account. The comparison analysis would be best done in the same seasonal period. Yet, once the observed area is relatively large, defining the reference value as the normal behavior may a bit tricky. The starting period of paddy transplantation may differ from one area to another. Thus, the calculation of start-end growing season, length of growing, and the mean behavior may take a considerable observation.
- The persevered atmospheric noise from cloud or haze after the smoothing or filtering phase may affect the spectral values of indices and thus affect the anomaly values as well.

6. CONCLUSION AND RECOMMENDATION

6.1 Conclusion

6.1.1 Agricultural Drought Occurrences

Based on the analysis from the NDVI and NDDI temporal-histogram during a paddy growing season, on 50 samples rain-fed paddy field; it is concluded that the District of Gunungkidul did not experience a severe agricultural drought during the years of 2000 – 2014.

The productivity had not experienced a devastating condition affected by the several anomalies years in 2003 – 2005, 2007, 2009, and 2011 – 2012. Though, this deviated condition from the normal behavior was corresponded to the decreasing productivity of rain-fed paddy.

The anomalies were corresponded to some indication that are:

- The delay on the onset of the 1st paddy growing season in 2005, 2006, 2007, 2011, and 2013. The worst delay happened in 2006 (delayed for 49 days from the normal condition); and for the 2nd paddy growing season, the worst delay happened in 2007 (delayed for 33 days from normal condition). These lag was affected firstly by the delay in the 1st growing season on 2005
- The shorter day of paddy growing season was the indication of low rainfalls that affected the rain-fed paddy growing season. It was found that the shorter growing periods in 2005 – 2006, as well as in 2012 were corresponded to the low performance of rain-fed paddy photosynthetic-activity.
- The NDVI low amplitudes and NDDI high amplitudes in 2004 – 2005, 2007, and 2012 were corresponded to another dryness indication. Low amplitude in NDVI showed the low variability between minimum-maximum values of NDVI, while high amplitude in NDDI showed the high variability between minimum-maximum values of NDDI.

- The deviated anomaly values of rain-fed paddy productivity happened in years of 2002, 2004 – 2005, 2007, 2009 – 201, and 2013. In 2013, the deviated productivity was related to the farming activity of paddy-variety change. While the other anomaly years were more related to the low performance of photosynthetic activity.

6.1.2 Agricultural Drought Spatial Occurrences

Spatially, six sub-districts were not included in the overall analysis of indices profile due to its physical condition. Sub-districts of Purwosari, Girisubo, Saptosari, Tepus, Tanjungsari, and Rongkop are located in the Southern Gunungkidul that mostly karstic area of conical limestone and marl. This condition affects to the area of rain-fed paddy field that is not as wide as the other part of Gunungkidul District. Moreover, these 6 sub-districts also did not meet the requirement of 70% coverage within one MOD09A1 pixel size.

This research showed sub-districts that experienced poor vegetation performance in anomaly years. Sub-districts of Paliyan, Wonosari, and Panggang were commonly experienced the lower performance of photosynthetic activity from paddy greenness that lower than the NDVI normal condition, and higher than the NDDI normal condition.

However, from the annual mean values of NDVI and NDDI anomaly; generally all sub-districts experienced a slight decline from the indices' normal behavior. Yet, those three sub-districts experience a higher deviation than the other sub-districts.

6.1.3 Comparative Assessment of NDVI and NDDI with the Rain-fed Productivity

The performance of the NDVI and NDDI in detecting the agricultural drought was evaluated by correlating indices performance to the rain-fed paddy productivity. From the comparative assessment, this research concluded that NDDI had a relatively stronger correlation to the rain-fed productivity than the NDVI.

The NDDI was found outperform the NDVI in terms of indices' mean values (38.19 %), normal behavior (82.60 %), and standardized (z-score) anomaly values (0.2628); While NDVI to paddy productivity correlated 32.51 % in indices' mean values, -68.55 % in normal behavior, and -0.51 in standardized (z-score) anomaly values.

Taking everything into consideration, NDDI could be suggested as a better index to indicate the agricultural drought, corresponds to its stronger relation with the crop productivity.

6.2 Recommendation

For a further study, there is a chance to conduct a research by combining this comparison assessment with a better and a more detail rainfall data. This would be beneficial to support and promote the use of NDDI in indicating the agricultural drought by associating it with the meteorological drought assessment.

ANNEX

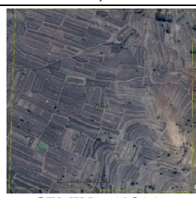
Annex 1a. 21 Location Samples for Indices Profiling,
Taken from ≥ 95% Rain-fed Paddy Field Coverage in One MOD09A1 Pixel-size.

NO.	SUB-DISTRICT	NUMBER OF SAMPLE	PIXEL NUMBER	% COVERAGE	COORDINATE	
					X	Y
1	PALIYAN	2	7,220	100.01	450325.91768	9115842.02812
2			7,367	100.01	450789.23040	9116305.34084
3	WONOSARI	10	7,525	100.01	456348.98300	9116768.65356
4			7,526	100.01	456812.29572	9116768.65356
5			7,527	100.01	457275.60844	9116768.65356
6			7,528	100.01	457738.92115	9116768.65356
7			7,662	100.01	452179.16855	9117231.96627
8			7,673	100.01	457275.60844	9117231.96627
9			7,675	100.01	458202.23387	9117231.96627
10			7,808	100.01	452179.16855	9117695.27899
11			8,540	100.01	453106.33800	9119956.24000
12			8,542	100.01	454032.95200	9119956.23900
13	PLAYEN	3	8,974	100.01	451252.54312	9121401.78073
14			9,406	100.01	448472.66681	9122791.71888
15			9,993	100.01	449862.60496	9124644.96974
16	KARANGMOJO	2	9,720	100.01	458665.54659	9123718.34431
17			9,866	100.01	458665.54659	9124181.65703
18	SEMIN	2	12,528	100.01	474418.17896	9132521.28593
19			12,814	100.01	471638.30266	9133447.91137
20	NGAWEN	2	13,095	100.01	466541.86278	9134374.53680
21			13,241	100.01	466541.86278	9134837.84952

Annex 2b. 29 Location Samples for Indices Profiling,
Taken from ≥ 70% Rain-fed Paddy Field Coverage in One MOD09A1 Pixel-size.

NO.	SUB-DISTRICT	NUMBER OF SAMPLE	PIXEL NUMBER	% COVERAGE	COORDINATE	
					X	Y
22	GEDANGSARI	4	11460	87.64754563	453105.793982	9129278.096910
23			11461	75.83688415	453569.106700	9129278.096910
24			12781	81.68620392	456348.983002	9133447.911370
25			12922	70.67934487	454032.419416	9133911.224080
26	PONJONG	14	7689	89.26935973	464688.611907	9117231.966270
27			7836	87.20150017	465151.924624	9117695.278990
28			8584	84.32925574	473491.553530	9120011.842570
29			8729	87.29289373	473028.240814	9120475.155290
30			8875	81.30344991	473028.240814	9120938.468010
31			9009	73.72880562	467468.488209	9121401.780730
32			9010	77.9171141	467931.800927	9121401.780730
33			9022	76.38220273	473491.553530	9121401.780730
34			9023	88.0849558	473954.866248	9121401.780730
35			9156	93.27874443	467931.800927	9121865.093440
36			9170	76.09068379	474418.178964	9121865.093440
37			9461	76.72616685	473954.866248	9122791.718880
38			9462	94.20511327	474418.178964	9122791.718880
39			9741	79.81650611	468395.113643	9123718.344310
40	NGLIPAR	6	10739	73.15022773	457275.608436	9126961.533330
41			10749	71.43526618	461908.735606	9126961.533330
42			11469	72.78216663	457275.608436	9129278.096910
43			11482	75.81215107	463298.673757	9129278.096910
44			12355	91.96084805	461908.735606	9132057.973220
45			12501	83.83672169	461908.735606	9132521.285930
46	PANGGANG	1	6473	75.44107313	442449.601491	9113525.464540
47	SEMANU	1	7394	73.68690427	463298.673757	9116305.340840
48	PATUK	3	11145	80.41186085	442449.601491	9128351.471480
49			11296	77.2997228	444766.165076	9128814.784200
50			11593	83.20907994	447082.728661	9129741.409630

Annex 2a. 21 Location Samples for Indices Profiling,
Based on ≥ 95% Rain-fed Paddy Field Coverage in One MOD09A1 Pixel-size.

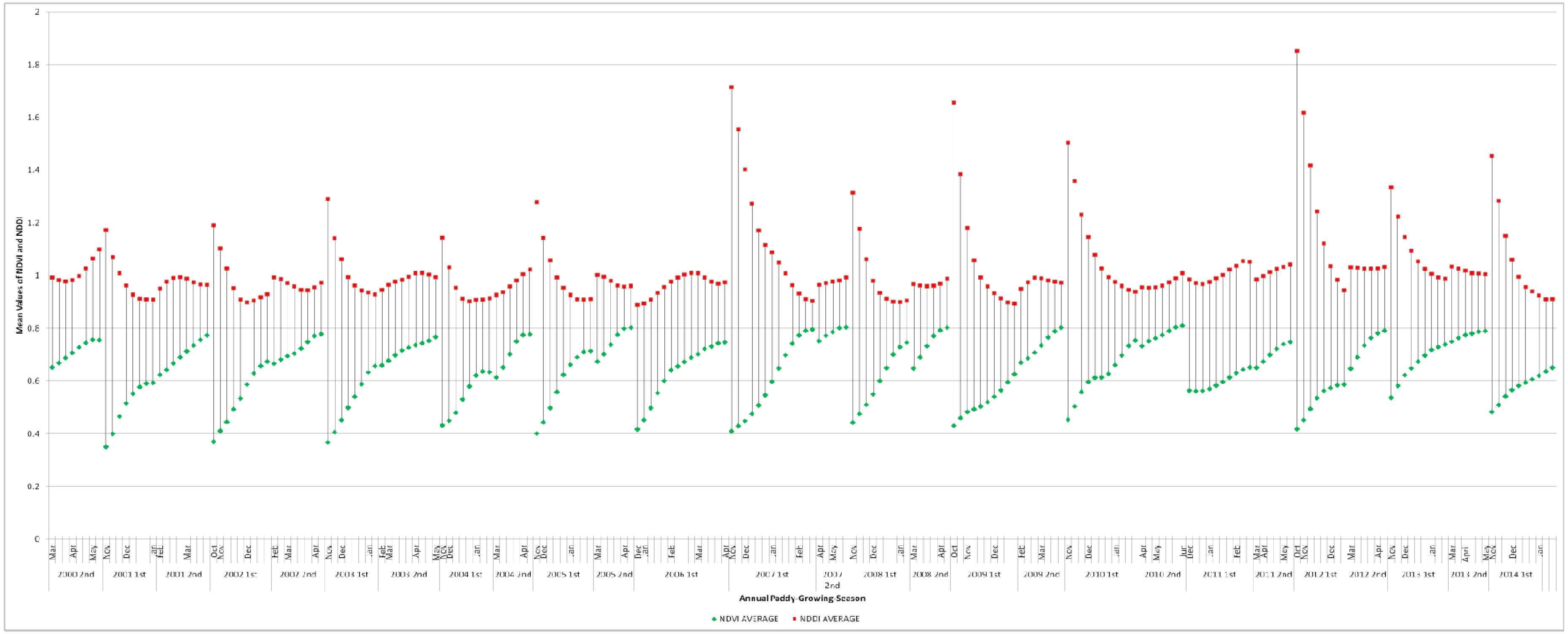
 PALIYAN – 7220 Oct 8th, 2013	 PALIYAN – 7367 Oct 8th, 2013	 WONOSARI – 7525 Oct 8th, 2013	 WONOSARI – 7526 Oct 8th, 2013	 WONOSARI – 7527 Oct 8th, 2013
 WONOSARI – 7528 Oct 8th, 2013	 WONOSARI – 7662 Oct 8th, 2013	 WONOSARI – 7673 Oct 8th, 2013	 WONOSARI – 7675 Oct 8th, 2013	 WONOSARI – 7808 Oct 8th, 2013
 WONOSARI – 8540 Sept 10th, 2013	 WONOSARI – 8542 Sept 10th, 2013	 PLAYEN – 8974 Oct 8th, 2013	 PLAYEN – 9406 Oct 8th, 2013	 PLAYEN – 9993 Oct 8th, 2013
 KARANGMOJO – 9720 Oct 8th, 2013	 KARANGMOJO – 9866 Oct 8th, 2013	 SEMIN – 12528 Oct 8th, 2013	 SEMIN – 12814 Oct 8th, 2013	 NGAWEN – 13095 Oct 8th, 2013
 NGAWEN – 13241 Oct 8th, 2013				

Source: DigitalGlobe, CNES/Astrium – Google Earth

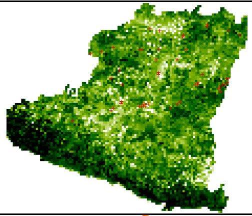
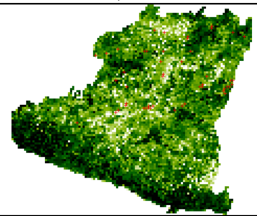
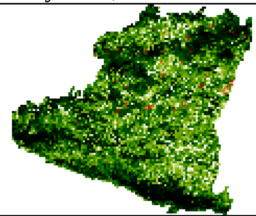
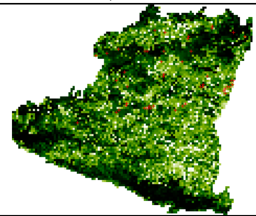
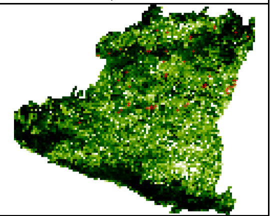
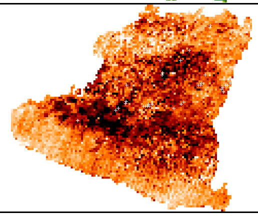
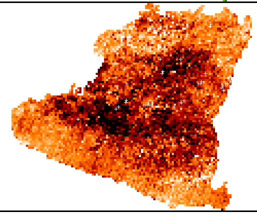
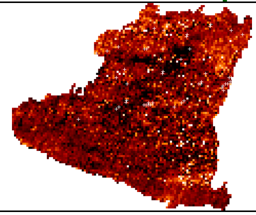
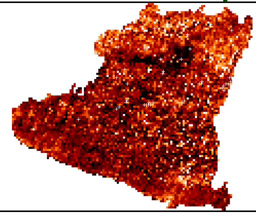
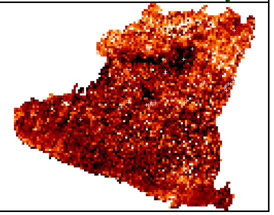
Annex 2b. 29 Location Samples for Indices Profiling,
Based on ≥ 70% Rain-fed Paddy Field Coverage in One MOD09A1 Pixel-size.

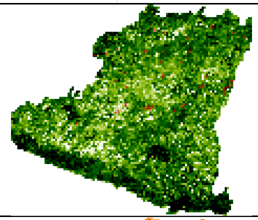
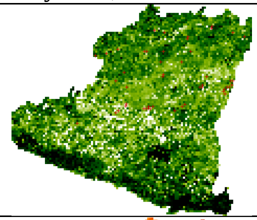
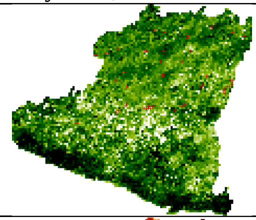
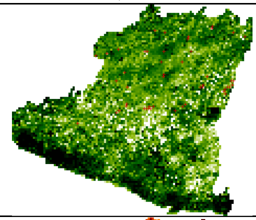
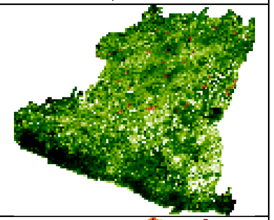
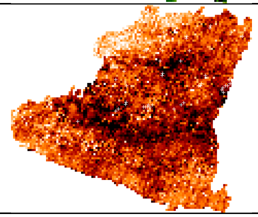
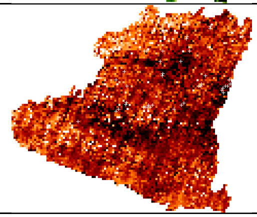
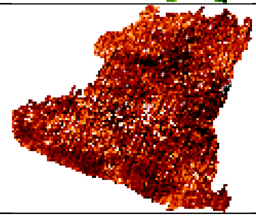
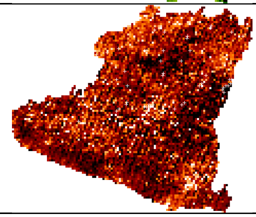
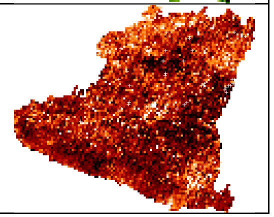
Source: DigitalGlobe, CNES/Astrium – Google Earth

Annex 3 Mean Values of NDVI (Green Dots) and NDDI (red dots)
from 50 sample locations within a Paddy Growing Season, Year 2000 – 2014



Annex 4 Temporal images of greenness performance during the anomaly occurrence in 2005, 2007, and 2010

	DOY: 321, Nov 17th 03	DOY: 329, Nov 25th 03	Doy: 361, Dec 27th 03	DOY: 1, Jan 01st 04	DOY: 9, Jan 09th 04
NDVI					
NDDI					

	DOY: 321, Nov 17th 05	Doy: 337, Dec 03rd 05	Doy: 353, Dec 19th 05	DOY: 361, Dec 27th 05	DOY: 1, Jan 01st 06
NDVI					
NDDI					

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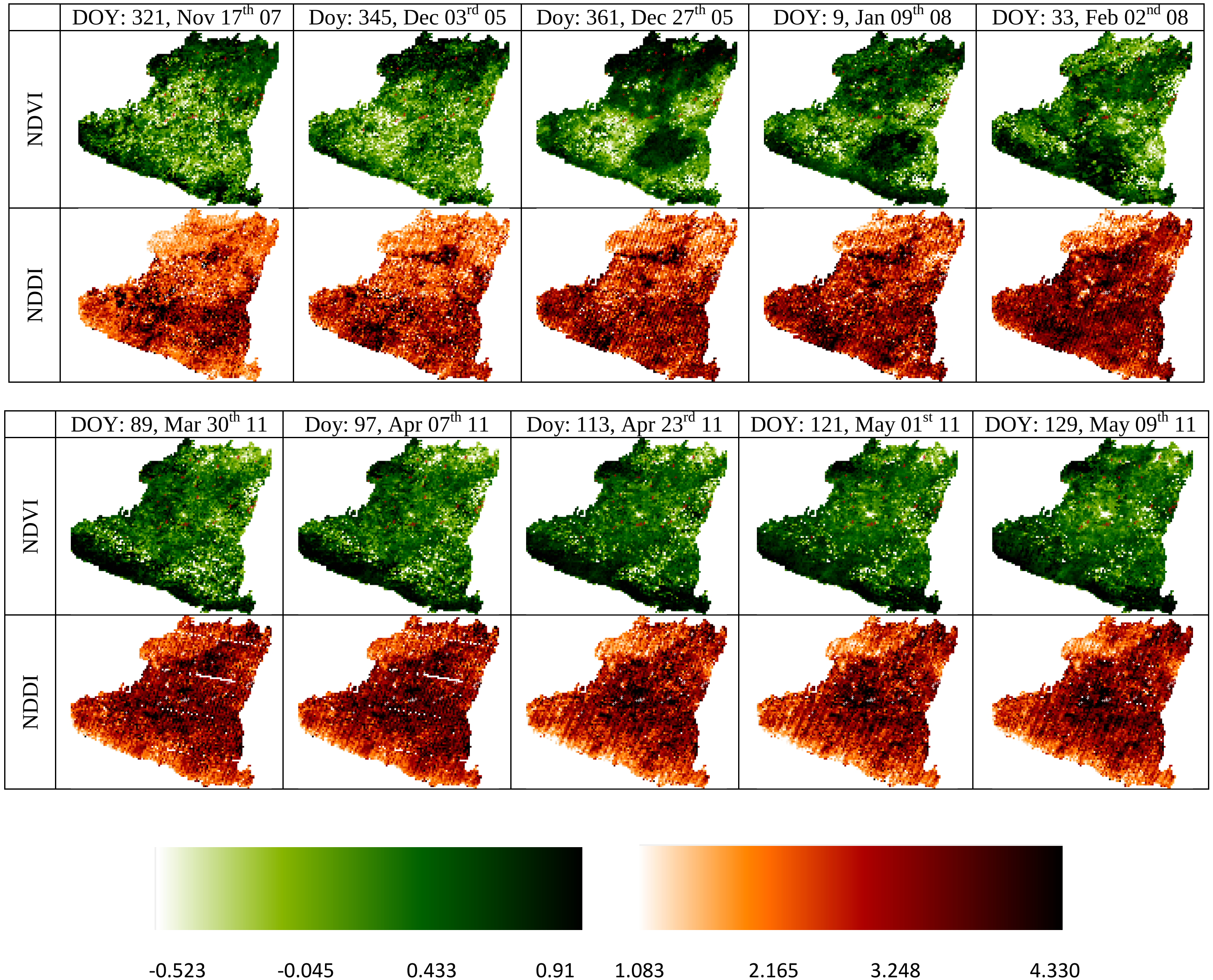
DOY: 321, Nov 17th 07
Doy: 345, Dec 03rd 05
Doy: 361, Dec 27th 05
DOY: 9, Jan 09th 08
DOY: 33, Feb 02nd 08
NDVI
NDDI
DOY: 89, Mar 30th 11
Doy: 97, Apr 07th 11
Doy: 113, Apr 23rd 11
DOY: 121, May 01st 11
DOY: 129, May 09th 11
NDVI
NDDI
-0.523
-0.045
0.433
0.91
1.083
2.165
3.248
4.330

Annex 5 Rain-fed Paddy Productivity (Quintals/Ha) By Sub-districts, Year 1997 – 2013

NO	SUB-DISTRICT	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Average (Qu/Ha)
1	PANGGANG	32.31	27.28	25.05	31.36	31.47	30.65	31.64	32.41	27.68	36.28	36.09	42.91	42.91	42.64	42.87	45.95	46.95	35.67353
2	PALIYAN	35.8	35.68	43.25	37.6	31.33	32.42	37.79	35.02	39.17	44.19	36.13	38.34	43.82	40.58	44.43	47.4	45.22	39.30412
3	SEMANU	35.91	38.46	45.19	42.33	31.86	34.32	37.68	41.66	43.74	47.92	47.35	47.75	50.38	47.48	47.72	52.45	49.21	43.61235
4	PONJONG	35.68	34.76	34.4	40.53	31.14	31.03	33.27	36.53	37.23	43.21	43.5	43.6	45.12	44.29	45.82	46.78	43.24	39.41941
5	KARANGMOJO	35.03	37.02	40.22	44.29	31.16	28.43	30.78	37.09	38.34	47.37	39.92	53.15	51.21	48.31	48.07	53.24	44.79	41.67176
6	WONOSARI	36.62	34.12	44.47	34.68	31.63	35.74	40.28	39.17	35.85	46.34	38.95	42.91	44.57	48.44	48.42	55.1	49.22	41.55941
7	PLAYEN	34.53	34.16	36.94	38.47	31.72	34.33	40.27	45.12	39.57	46.07	39.84	47.2	44.5	45.68	46.57	53.31	47.92	41.54118
8	PATUK	29.17	26.46	35.88	21.76	31.15	31.17	36.6	32.47	26.8	36.22	36.95	37.37	41.52	41.52	41.52	54.09	48.45	35.82941
9	GEDANG SARI	-	-	42.31	35.63	31.81	24.94	37.34	41.8	35.99	39.47	43.19	49.83	50.52	40.31	43.45	52.36	46.68	41.042
10	NGLIPAR	35.22	40.57	36.86	43.77	31.34	26.54	37.44	43.85	27.82	38.4	38	54.81	42.91	39.84	42.5	45.91	48.12	39.64118
11	NGAWEN	32.64	46.4	43.92	48.13	31.28	36.16	37.44	44.98	27.96	46.82	38.06	44.57	48.42	50.52	43.71	49.39	50.55	42.40882
12	SEMIN	34.29	41.36	38.42	41.17	31.68	34.5	30.5	36.96	30.19	43.12	40.42	40.14	42.08	43.6	42.73	49.91	43.49	39.09176
13	PURWOSARI	-	-	-	-	-	28.4	28.73	32.53	30.59	36.12	33.91	37.37	38.09	39.17	42.04	45.12	40.03	36.00833
14	SAPTOSARI	-	-	-	38.27	31.28	34.36	34.78	30.37	29.07	42.92	36.97	37.79	41.52	41.37	41.39	42.22	35.99	37.02143
15	TEPUS	32.65	32.96	30.99	28.31	31.17	30.38	35.75	36.56	30.45	38.7	37.99	38.2	40.97	41.13	40.83	43.3	38.97	35.84176
16	TANJUNGSARI	-	-	-	-	-	29.79	37.14	40.55	39.17	38.17	38.2	38.76	41.87	44.98	45.54	45.9	44.29	40.36333
17	RONGKOP	32.53	30.09	36.66	30.65	31.11	32.86	36.13	34.6	35.57	45.02	36.57	40.56	46.51	46.44	45.54	47.12	46.42	38.49294
18	GIRISUBO	-	-	-	-	-	26.23	33.43	34.88	36.96	40.84	36.81	40.56	42.77	42.77	44.91	45.2	49.07	39.53583
Total		442.38	459.32	534.56	556.95	471.13	562.25	636.99	676.55	612.15	757.18	698.85	775.82	799.69	789.07	798.06	874.75	818.61	708.06
Annual Average (Qu/Ha)		34.03	35.33	38.18	37.13	31.41	31.24	35.39	37.59	34.01	42.07	38.83	43.10	44.43	43.84	44.34	48.60	45.48	39.34

Annex 6 Rain-fed Paddy Field Area in District of Gunungkidul, Province of Yogyakarta Special Region

Ponjong			
Semanu			
Semin			
Nglipar			
Ngawen			
Paliyan			
Pathuk			
Gedangsari			
Playen			
Karangmojo			
Wonosari			

Panggang			
Saptosari			
Tanjungsari			
Tepus			
Girisubo			
Rongkop			

Annex 7 The Anomaly Values of NDVI and NDDI by Sub-district, Year 2001 – 2013

Sub-District	2001		2002		2003		2004		2005		2006		2007		2008		2009		2010		2011		2012		2013	
	NDVI	NDDI	NDVI	NDDI	NDVI	NDDI	NDVI	NDDI	NDVI	NDDI	NDVI	NDDI	NDVI	NDDI	NDVI	NDDI	NDVI	NDDI	NDVI	NDDI	NDVI	NDDI	NDVI	NDDI	NDVI	NDDI
PALIYAN	-4.53	0.67	0.43	1.04	-2.02	1.41	-1.70	6.36	-2.13	3.58	0.05	-0.70	-0.76	3.18	-1.31	0.77	-1.15	1.67	-0.56	2.55	-0.03	0.03	-1.20	3.17	0.59	1.21
KARANGMOJO	-3.15	0.52	-0.10	-0.11	-0.14	0.83	-1.77	4.07	-0.01	2.06	0.98	-1.02	0.11	2.84	0.36	0.47	0.02	-0.17	1.75	0.18	-0.45	-0.18	-0.06	1.87	1.88	0.49
PLAYEN	-1.36	-0.92	-0.88	-0.34	-0.64	0.10	-0.39	0.48	-1.55	1.80	-1.09	-0.94	0.03	1.31	-0.73	-0.35	-0.14	0.39	1.01	0.06	-0.04	-0.06	0.07	1.36	1.14	0.43
NGAWEN	-3.00	-0.84	0.05	-1.40	-0.54	1.05	-0.98	0.57	-0.45	0.45	-0.06	-1.78	-0.13	1.77	1.02	-0.36	-1.07	0.12	0.84	-0.13	-2.11	-0.80	-0.56	1.82	2.76	-1.01
SEMIN	-2.11	-0.62	0.38	-0.63	0.61	-0.14	-0.02	0.33	1.08	-0.94	-0.19	-0.97	0.64	0.68	1.47	0.00	0.46	-0.27	0.87	0.37	-1.03	-0.10	0.14	0.66	1.81	-0.20
WONOSARI	-3.92	-0.78	-0.82	-0.25	-2.13	1.78	-1.93	1.78	-1.07	2.18	-0.32	-0.99	-0.38	2.77	-0.17	0.40	-0.84	0.77	-0.01	0.92	0.22	-0.10	-0.94	3.55	0.95	0.95
GEDANGSARI	-4.05	-2.06	-0.40	-1.87	-0.01	-1.08	-0.97	0.44	0.41	-1.62	-0.55	-1.77	-0.08	-0.01	0.87	-0.74	0.01	-0.61	1.35	-1.05	0.26	-1.05	0.01	0.60	1.94	-0.66
PONJONG	-3.23	-0.67	-0.93	-0.50	-0.08	-0.22	-1.29	1.03	-0.57	0.31	-0.11	-0.57	0.52	1.38	0.04	-0.11	-0.12	0.04	1.25	0.24	0.04	-0.16	-0.03	1.52	1.33	0.24
NGLIPAR	-2.38	-0.16	-0.82	-0.20	0.07	0.73	-0.97	1.65	-0.48	0.57	-0.44	-0.74	0.35	0.98	0.70	-0.14	-0.28	0.00	1.26	0.16	0.33	-0.18	0.19	1.15	1.65	0.02
PANGGANG	-2.57	0.58	-0.60	0.24	0.10	1.72	-0.49	0.78	-0.66	1.26	-1.37	0.16	-0.13	6.02	-0.36	1.14	-0.67	1.54	1.98	0.34	0.74	0.10	-0.30	4.26	-0.06	0.33
SEMANU	-2.89	-1.49	-1.12	-1.15	-0.17	0.33	-0.71	0.65	-1.88	1.44	1.73	-1.12	-0.03	1.40	-0.74	-0.73	-0.85	0.09	-0.10	-0.21	-0.24	-0.27	-0.97	1.18	0.32	0.72
PATUK	-1.49	-2.77	-0.74	-2.25	-0.59	-2.25	-1.31	-1.38	-0.89	-0.95	-0.43	-1.78	0.36	-0.38	0.98	-1.05	-0.56	-1.02	1.01	-0.78	-0.01	-0.88	-0.70	0.03	1.65	-0.60

Annex 8 The Anomaly Values Rain-fed Productivity by Sub-district, Year 2001 – 2013

YEAR	PANGGANG	PALIYAN	SEMANU	PONJONG	KARANGMOJO	WONOSARI	PLAYEN	PATUK	GEDANG SARI	NGLIPAR	NGAWEN	SEMIN
2001	0.834	-2.193	-2.422	-2.113	-2.278	-1.409	-2.433	0.555	0.628	-2.340	-1.903	-2.495
2002	0.409	-1.118	-0.945	-1.410	-2.038	-0.129	-0.357	0.486	0.164	-2.563	-0.608	-0.753
2003	0.747	0.459	-0.072	-0.414	-0.988	1.016	2.431	1.674	0.893	0.304	-0.347	-1.751
2004	0.971	-0.343	0.870	0.712	0.346	0.599	3.445	0.449	1.057	1.491	0.892	0.239
2005	-1.041	0.893	1.278	0.888	0.574	-0.326	0.657	-0.832	0.569	-1.632	-1.990	-1.553
2006	2.535	2.296	2.089	2.911	2.433	2.606	2.289	1.362	0.750	0.411	1.165	1.895
2007	1.813	-0.277	1.536	2.111	0.519	0.239	0.381	1.346	0.936	0.317	-0.217	0.939
2008	3.595	0.321	1.408	1.722	2.901	1.163	2.057	1.278	1.299	3.356	0.769	0.798
2009	2.388	1.814	1.748	1.820	1.846	1.444	1.135	2.008	1.209	0.685	1.307	1.190
2010	1.861	0.728	0.995	1.387	1.186	2.162	1.282	1.685	0.449	0.219	1.494	1.430
2011	1.647	1.692	0.970	1.566	1.058	1.800	1.349	1.481	0.636	0.595	0.356	1.096
2012	1.986	2.232	1.757	1.591	1.677	2.850	2.560	3.504	1.206	1.072	1.186	2.591
2013	1.879	1.401	1.008	0.765	0.422	1.305	1.163	1.796	0.740	1.328	1.271	0.887

Annex 9 Form of Verification

1 Date :

2 Sub-district :

3 Sample No. :

4 Photo No. :

5 GPS Code :

6 Farmer's Name :

7 Rain-fed Paddy Field Area Extent (Ha) :

8 Landcover :

9 Types of Crop :

10 Paddy Growing Season (Paddy Calendar):

- ✓ 1st Planting: :
- ✓ 2nd Planting :
- ✓ Harvesting :

11 Productivity :

12 Farming System :

13 Drought History :

- ✓ When :
- ✓ Affected Location :
- ✓ Loss :

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