IDENTIFICATION OF INUNDATED AREA USING NORMALIZED DIFFERENCE WATER INDEX (NDWI) ON LOWLAND REGION OF JAVA ISLAND

Suwarsono[1*], Jalu Tejo Nugroho[1*], and Wiweka[1*]
[1]Center for Remote Sensing Application, Indonesian National Institute of Aeronautics and Space (LAPAN), Jl. Kalisari No.8, Pekayon, Pasar Rebo, Jakarta 13710 Indonesia
[*]Email: suwarsono@lapan.go.id or landsono@yahoo.com

Abstract. Flood disaster is a major issues due to its frequently events on several areas in Indonesia. Delineation of inundated area caused by flood is needed to support disaster emergency response. The objective of this research was to identify inundated areas using NDWI methos from Landsat TM/ETM^+ data on lowland regions of Java island. A pair of the data (before and during the flood) were in each observation areas. Observation areas were selected in several location of lowland regions of Java island where great event of flood occurred during the last decades. The thresholds values of NDWI change were used to separate the flood and non flood areas. The results showed that the extent of inundated area caused by flood on lowland regions can be identifyed and separated based on NDWI variables extracted from Landsat TM/ETM^+.

Keywords: *inundated area, NDWI, Landsat, lowland region, Java Island*

1 INTRODUCTION

Flood disaster is a major issues due to its damage and occur frequently in several areas of Indonesia. The lowland region of Java Island is a prone area for flooding. The region stretches along the northern coast, the center of the eastern part of Java (the intermountains plain) and the south coast of Central Java. Delineation the extent of inundated area caused by flood is needed as an important spatial information to support disaster emergency response. Flood disasters often cause damage physically, economically, socially and culturally. Demands on the development of information technology often raise issues such as how the flood affected area distribution can be determined in a faster way, precise, and accurate. Additionally, we to know those areas affected by a flood. Those questions are closely related to the data availability of land cover and infrastructure in a region. Remote sensing data are expected to be used to support flood mitigation efforts. One of the efforts is to provide fast and accurate information about the areas affected by the floods.

Many studies used remote sensing data to identify the inundation area. Anersen *et al*. (2013) presented a method for monitoring flood extent variation using ALOS ScanSAR images at the Curuai Lake floodplain, in the lower Amazon River, Brazil. In the research, twelve ScanSAR scenes were acquired between 2006 and 2010, including seven during the 2007 hydrological year. The research implemented a hierarchical, object-based classification algorithm, and was able to map land cover types and flooding status in the study area.

Ordoyne *et al*. (2008) tried to use the MODIS data to characterize seasonal inundation patterns in the Florida Everglades. In the study, empirical models to predict surface inundation in the Everglades were estimated using MODIS data calibrated to water stage data from the South Florida Water Management District for the calendar year of 2004. Several indices were tested, including the Normalized Difference Wetness Index and the diurnal land surface temperature difference, but the Tasseled Cap wetness index showed the strongest correlation to water stage data across a range of surface vegetation types. Yan *et al*. (2010) tried to develop a novel technique of monitoring tidal floods and their spatiotemporal dynamics using a time series combination of the MODIS vegetation indices (VIs). The vegetation indices, which included the enhanced vegetation index the difference in the values of EVI and LSWI (DVEL), were extracted from MODIS datasets with a spatial resolution of 500 m from 2001 to 2006. The research found that combined application of EVI, LSWI, and DVEL was suitable for monitoring flood inundation and recording flood dynamics and vegetation succession. Feng *et al*. (2012) has used the MODIS data to assess the inundation changes of Poyang Lake using observations between 2000 and 2010. The study demonstrated the unique value of MODIS medium resolution data and the FAI method in studying short-term and long term inundation changes for highly dynamic lakes such as Poyang Lake of China. Furthermore, Feng *et al*. (2012) stated that for the same reasons, the method used may be applied to other similar water bodies to study their potential response to climate change and human impact.

Recently, several methods were often used to detect the inundation area based on the normalized difference water index (NDWI) and improved of NDWI (Gao, 1996; McFeeters, 1996; Xu, 2006; and Yang *et al*., 2011). The method was reliable in separating between flood and non flood area using optical images. However, the utilization in flood-prone areas in Indonesia, this method has not yet proven its ability. Therefore, this research tried to identify the inundated area using NDWI and improved (EVI), land surface water index (LSWI) and of NDWI from Landsat TM/ETM$^+$ which applied on the flood prone region of Indonesia. Focus of the study sites selected were on lowland regions of Java Island. Almost every year during the rainy season these areas inundated by flood.

2 MATERIALS AND METHOD

2.1 Data

A pair of the data were chosen (before and during the flood) in each observation area. Observation area were selected in several location of lowland regions of Java Island where have occured great event of flood during last decades. We focused on three lowland region of Java Island, i.e., Downstream region of Citarum Watershed, Lowland of Purworejo, and Bengawan Solo (Figure 1). Administratively, Downstream region of Citarum Watershed is a part of West Java Province, Lowland of Purworejo is a part of Central Java Province, and Downstream of Bengawan Solo is a part of East Java Province. The third area is expected to represent the general condition of lowland region of Java. The areas to be flooded almost every year during rainy season. Therefore, we choose Landsat data that cover the areas i.e., Path/Row 118/65 for Bengawan Solo, 120/065 for Lowland of Purworejo areas and 122/064 for Citarum (Table 1).

Figure 1. Locations of study area.

Table 1. List of Landsat-7 ETM$^+$ of each study areas.

Study Area	Scenes No.	Before Flood	During Flood
Bengawan Solo	P118/R065	November 25, 2007	January 12, 2008
Citarum	P120/R065	March 2, 2010	April 19, 2010
Lowland of Purworejo	P122/R064	October 19, 2012	December 6, 2012

2.2 Data analyses

We used the NDWI parameter i.e., NDWI of Gao (1996), NDWI of McFeeters (1996), MNDWI of Xu (2006), and NWI of Yang *et al*. (2011) for detecting the inundation areas. Then, the thresholding method used to separate between flood and non flood. The normalized difference water index (NDWI), was proposed firstly for remote sensing of vegetation liquid water from space by Gao (1996). This index used radiances or reflectances from a red channel around 0.66 µm and a near-IR channel around 0.86 µm. The red channel was located in the strong chlorophyll absorption region, while the near-IR channel was located in the high reflectance plateau of vegetation canopies. The two channels sense very different depths through vegetation canopies. The normalized difference water index (NDWI) used two near-IR channels; one centered approximately at 0.86 µm, and the other at 1.24 µm. Following the simplicity of NDVI, the NDWI was defined as following (Gao, 1996):

$$NDWI = \frac{\rho(0.86\mu m) - \rho(1.24\mu m)}{\rho(0.86\mu m) + \rho(1.24\mu m)} \quad (1)$$

where, ρ(λ) is apparent reflectance, and λ is wavelength.

Water body extraction by using remote sensing has been the most important method in the investigation of water resources, flood hazard prediction assessment and water planning with fast and accurate (Yang *et al*., 2011). The Normalized Difference Vegetation Index (NDWI) was employed to reach the goal of isolating water and non-water features (Ho *et al*., 2010). There were several formula of NDWI that combine different pairs of bands from Landsat TM or ETM. Therefore, according to Gao (1996), the formula of NDWI could be composed by using the NIR and short wave infrared (SWIR) (band4 and band5). Mcfeeters (1996) used green and near infrared (NIR) (band 2 and band 4). Both formulas of NDWI as follows:

$$NDWI = \frac{\rho 4 - \rho 5}{\rho 4 + \rho 5} \quad \text{(Gao, 1996)} \quad (2)$$

$$NDWI = \frac{\rho 2 - \rho 4}{\rho 2 + \rho 4} \quad \text{(McFeeters, 1996)} \quad (3)$$

Xu (2006) demonstrated the new NDWI was called MNDWI (Modified NDWI). Because, NDWI derived from McFeeters give positive values for urban areas simultaneously as the reflectance pattern of urban areas was coincident with that of water in green and NIR band (band 2 and band 4). Moreover, in MIR (band 5) the reflectance of urban areas was much higher than that of green band, while use of band 5 instead of band 4 for NDWI measurement significantly avoided the confusion of water and urban extraction with positive values of water and negative value of other features including urban. The MNDWI formula from Xu (2006) as below:

$$MNDWI = \frac{\rho 2 - \rho 5}{\rho 2 + \rho 5} \quad \text{(Xu, 2006)} \quad (4)$$

Yang *et al.* (2011) proposed the New Water Index (NWI) as new index for water body extraction. NWI was proposed on the basis of further finding and analysis of water's and other ground objects' spectrum feature in the Landsat ETM+. NWI used blue band, near infrared band, and mid-infrared band at the same time. The NWI formula as follows (Yang *et al*., 2011):

$$NWI = \frac{[\ (\rho 1 - (\rho 4 + \rho 5 + \rho 7)\ ]}{[\ (\rho 1 + (\rho 4 + \rho 5 + \rho 7)\ ]} \qquad (5)$$

3 RESULTS AND DISCUSSION

Landsat imagery before and during flood event in Bengawan Solo Downstream, Purworejo regency, and Citarum Downstream before applying the three algorithm were presented in Figure 2, 3, and 4. From these images, we could see the general inundation in all three regions.

The estimation results fo NDWI, MNDWI, and NWI values in some samples in the three regions, in the pre-flood, during flood and the change values was displayed in Table 2. Overall, the value of NDWI 1, NDWI 2, MNDWI and NWI increased in the event of flooding. NDWI 1 was NDWI model from Gao (1996), NDWI 2 was NDWI model from McFeeters (1996). Based on these data, we determined the threshold value for inundated areas. Based NDWI method of Gao (1996), a pixel was declared as floodwaters if requirements were met: if NDWI$_{(\text{during flood-before flood})}$>=0.094 and NDWI$_{(\text{during flood})}$>=0.161. With NDWI method of McFeeters (1996), a pixel was declared as floodwaters if requirements were met: if NDWI$_{(\text{during flood-before flood})}$>=0.228 and NDWI$_{(\text{during flood})}$>=0.548. When using the method MNDWI of Xu (2006), a pixel was declared as floodwaters if requirements were met: if MNDWI$_{(\text{during flood-before flood})}$>=0.498 and MNDWI$_{(\text{during flood})}$>=0.650. While using the method NWI of Yang *et al*. (2011), a pixel was declared as floodwaters if requirements were met: if NWI$_{(\text{during flood-before flood})}$>=0.501 and NWI$_{(\text{during flood})}$>=0.376.

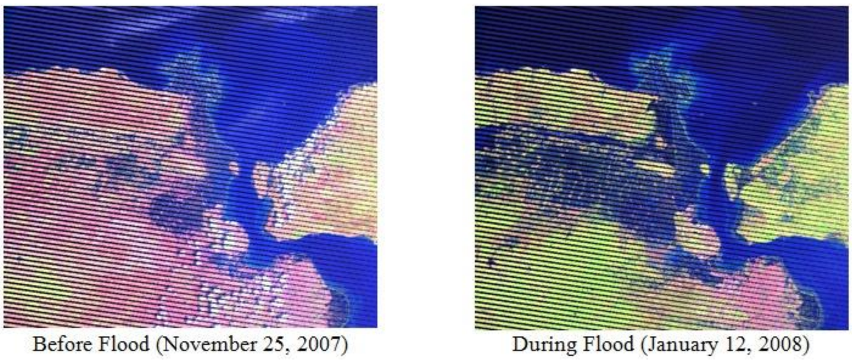

Figure 2. Landsat-7 ETM+ imageries of a part areas of Bengawan Solo downstream, date before and during flood. Displayed in natural color composite RGB 542.

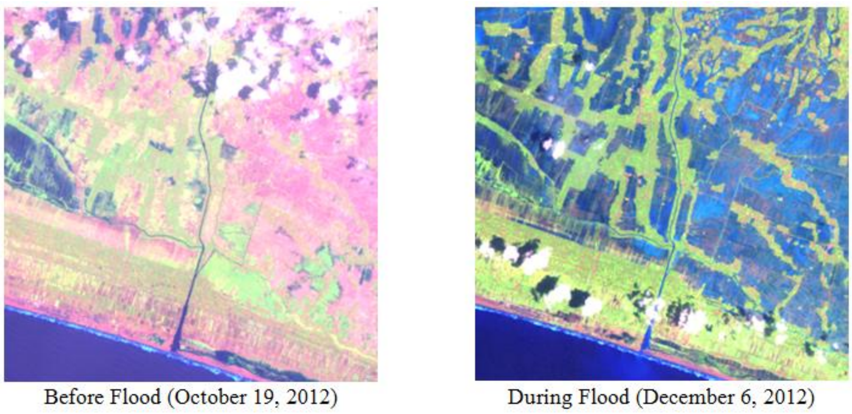

Figure 3. Landsat-7 ETM+ imageries of lowland region of Purworejo Regency, date before and during flood. Displayed in natural color composite RGB 542.

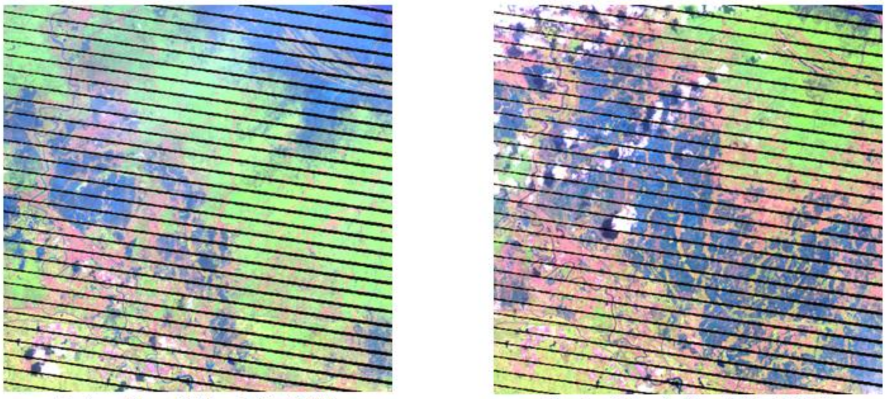

Figure 4. Landsat-7 ETM+ imageries of a part areas of Citarum downstream, date before and during flood. Displayed in natural color composite RGB 542.

Table 2. NDWI values of flood in all site.

Periods	NDWI	Mean	Dev.Std
Before Flood	pre-NDWI 1	0.141	0.008
	pre-NDWI 2	0.138	0.252
	pre-MNDWI	0.084	0.310
	pre-NWI	0.376	0.180
During Flood	during-NDWI 1	0.161	0.153
	during-NDWI 2	0.548	0.279
	during-MNDWI	0.650	0.314
	during-NWI	0.307	0.183
Change	Δ NDWI 1	0.302	0.208
	Δ NDWI 2	0.410	0.181
	Δ MNDWI	0.734	0.235
	Δ NWI	0.684	0.183

Figure 5 to 7 showed the application of the four methods on the lowland of Bengawan Solo, Purworejo Regency, and Citarum. Looking at the results of the application of some of these methods, each method produced different results with each other. Visually, the NDWI method of McFeeters provided more appropriate results when compared to other three methods. This could be explained that the NDWI method of McFeeters aimed to (1) magnify the higher reflectance value of water in green band; (2) diminish the low reflectance value of water in NIR band; and (3) make use of the distinguished contrast between water and land of NIR band (Ho *et al*., 2010).

McFeeters method produced more accurate results because the study area was dominated by rice fields. Conditions of land use in the three regions was dominated by rice fields. This model was sensitive to detect the changes in land from non-water become to water. This model could not explain, if detected puddle was a puddle of water due to flooding or other effects, such as water-logging during rice cultivation. This condition was a weakness of inundation area detection automatically using the parameters NDWI. Therefore, to perform the detection of inundation areas due to flooding, further research not only based on one variable NDWI is needed.

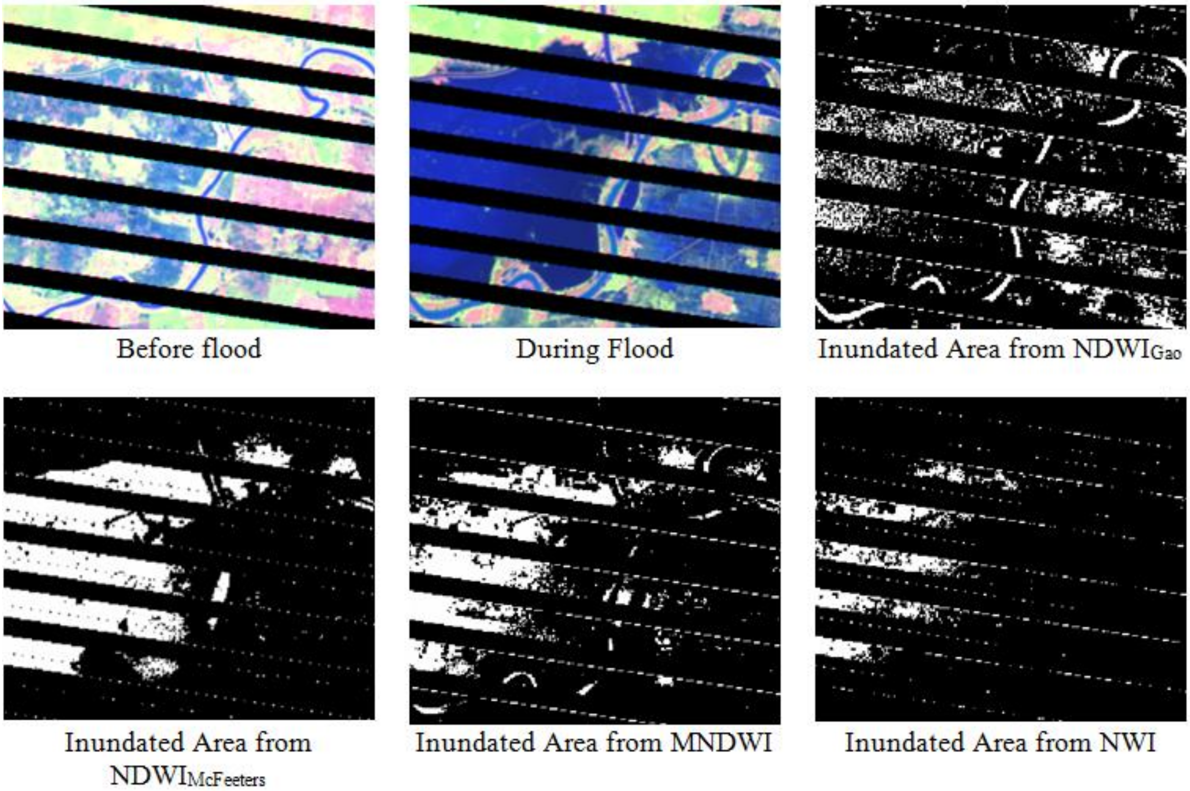

Figure 5. Inundated area in Lowland of Bengawan Solo Downstream extracted from several Methods.

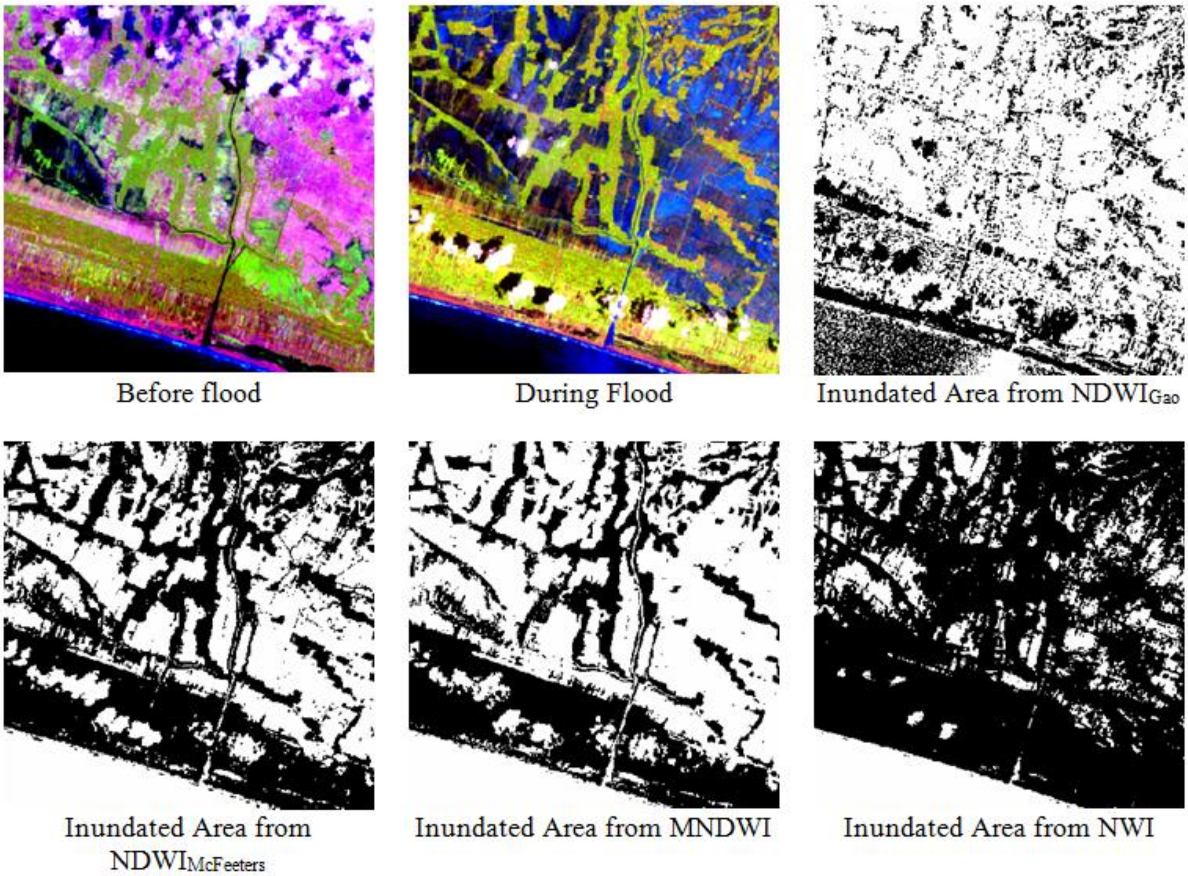

Figure 6. Inundated area in Lowland of Purworejo extracted from several methods.

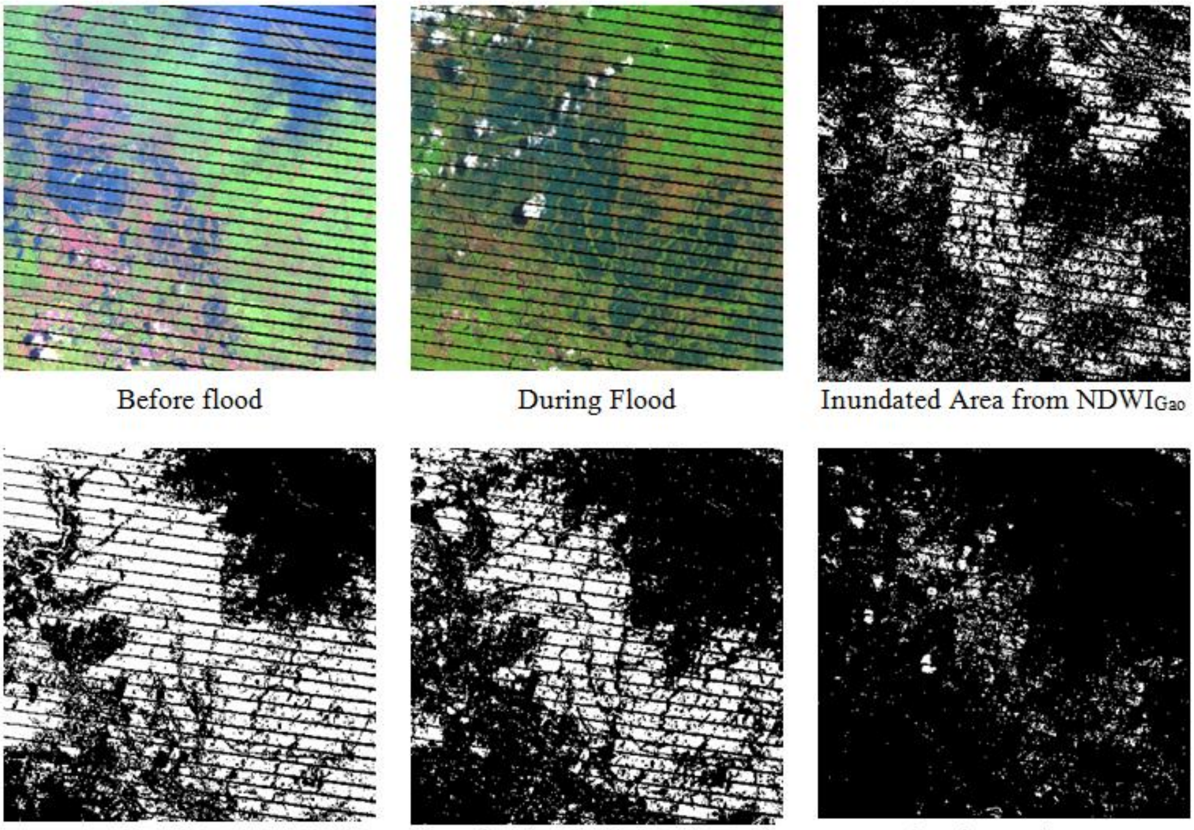

Figure 7. Inundated area in lowland of Citarum Downstream extracted from several methods.

4 CONCLUSION

The extent of inundated area caused by flood on lowland regions can be identified and separated based on NDWI, MNDWI, and NWI variables extracted from Landsat TM/ETM+. Visually, the results showed that NDWI method of McFeeters provided more appropriate results when compared to the other three methods. Floodwaters detection results using the water index could mix with the water which was not from the flood (water-logging during rice cultivation). Therefore, further research based not only by one variable NDWI is needed to perform the detection of inundation areas due to a flood event.

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