DETECTING SURFACE WATER AREAS AS ALTERNATIVE WATER RESOURCE LOCATIONS DURING THE DRY SEASON USING SENTINEL-2 IMAGERY (CASE STUDY: LOWLAND REGION OF BEKASI-KARAWANG, WEST JAVA PROVINCE)

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Abstract. In Indonesia, drought is a type of disaster that often occurs, especially during the dry season. What is most needed at such times is the availability of sufficient water sources to meet shortages. Therefore, water source locations are vital during the dry season in order to meet needs. To meet this information need, remote sensing data offer a precise solution. This research proposes a rapid method of detecting surface water areas based on remote sensing image data. It focuses on the use of remote sensing satellite imagery to detect objects and the location of surface water sources. The purpose of the study is to rapidly identify objects and locate surface water sources using Sentinel-2 MSI (MultiSpectral Instrument), one of the latest types of remote sensing satellite data. Several water index (WI) methods were applied before deciding which was most suitable for detecting surface water objects. The lowland region of Bekasi-Karawang, a drought prone area, was designated as the research location. The results of the research show that by using Sentinel-2 MSI imagery, MNDWI (Modified Normalized Water Index) is the appropriate parameter to detect surface water areas in the lowland region of Bekasi-Karawang, West Java Province, Indonesia, during times of drought. The method can be employed as an alternative approach based on remote sensing data for the rapid detection of surface water areas as alternative sources of water during the dry season. The existence of natural water sources (swamps, marshes, ponds) that remain during this time can be used as alternative water resources. Further research is still needed which focuses on different geographical conditions and other regions in Indonesia.

Keywords: *surface water area, drought, Bekasi-Karawang, Sentinel-2, Normalized Difference Water Index (NDWI)*

1 INTRODUCTION

In Indonesia, drought is a type of disaster that often occurs, especially during the dry season. It puts people's lives at risk, particularly those who live in drought-prone areas. The consequences include concerns over water and food security, as well as financial risks and budgetary challenges, especially for developing countries in general (Wilhite, 2005; Godfray et al., 2010).

Droughts are generally grouped into meteorological, agricultural, hydrological, and socioeconomic types (Wilhite, 2005). All types of droughts can be related to a sustained precipitation deficit. However, diverse components of the hydrologic cycle respond to droughts differently (AghaKouchak et al., 2015).

The most important issue during a drought is the availability of sufficient water sources to meet demand. At the time of droughts, it is vital that

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information on the location of the water sources can be obtained quickly, thoroughly and accurately. Freshwater sources in the dry season can be in the form of ground water and surface water (such as lakes, swamps, rivers, and ponds). Knowledge of water source locations is vital during the dry season. So, the spatial information about water source location will be very important. In order to meet this information, remote sensing data offers a precise solution.

Several studies have shown that optical satellite imagery can be successfully used to identify surface water features based on spectral water indices, known as the Normalized Difference Water Index (NDWI) (McFeeters, 1996; Rogers & Kearney, 2004; Xu, 2006; Ding, 2009; Wang et al., 2017; Du et al., 2012; Li et al., 2013; Ashraf et al., 2015; Du et al., 2012; Du et al., 2014; Szabo et al., 2016; Yulianto et al., 2018; Kwang et al., 2018; Sekertekin et al., 2018; Suwarsono et al., 2013, 2020).

The NDWI was first proposed by Gao (1996) and used to detect the liquid water content of vegetation canopies. It is measured using Near Infrared (NIR) 0.86 μm and Short Wave Infrared (SWIR) 1.24 μm wavelengths (Equation 1-1).

$$NDWI = \frac{\rho 0.86 - \rho 1.24}{\rho 0.86 + \rho 1.24} \qquad (1\text{-}1)$$

McFeeters (1996) developed NDWI by using green and NIR reflectances (Equation 1-1), with further development by Rogers and Kearney (2004) by using red and SWIR reflectances. Xu (2006) proposed a modified NDWI (MNDWI), in which the SWIR band is utilised to replace the NIR channel in McFeeters NDWI method. Ding (2009) developed the new water index (NWI) using four spectral bands (blue, NIR, SWIR short, and SWIR long).

The NDWI model has been employed by several researchers to detect surface water, with varying results. Li et al. (2013) found that McFeeters NDWI and Xu's MNDWI could extract water body information more accurately, quickly and easily than supervised/unsupervised classification methods. Xu (2006) showed that MNDWI could enhance water bodies and suppress built-up features more efficiently than NDWI. In addition, Yulianto et al. (2018) found that MNDWI was the most appropriate parameter to use to detect flooded areas in the Bandung basin, which had heterogeneous land surface conditions. However, in detecting surface water reservoirs, Sekertekin et al. (2018) and Suwarsono et al. (2020) found that NDWI produced more accurate results than MNDWI.

Considering the results of the studies mentioned above, this research offers a rapid method of detecting surface water areas using remote sensing image data, and by applying several NDWI methods. We used Sentinel-2 MSI, one of the latest types of remote sensing satellite data. The lowland region of Bekasi-Karawang (Fig.1), a drought prone area, was designated as the research location.

2 MATERIALS AND METHODOLOGY

2.1 Location and Data

The research location is part of the downstream Citarum area. Administratively, the research sites are included in the lowland region of Bekasi-Karawang, a drought prone area, in West Java Province. The area is one of the national rice granary regions, which often experience drought in the dry season. In the area, water is needed for various purposes, including domestic, industrial, and agricultural. The area is representative of other lowland regions on the north coast of Java Island, which stretches from Serang (Banten) to Situbondo (East Java), which experience problems related to drought in the dry season. Figure 2-1 shows the location of the study area.

Sentinel-2 MSI Level 1C (MSIL1C) data were used in the research, with an acquisition date of 21 September 2020 and coverage area of 106:48:22.02 E/ 5:52:26.44 S (top left) - 107:48:0.2 E/ 6:24:49.9 S (bottom right). This area covers most of the lowland region of Bekasi-Karawang. The date was chosen because besides corresponding to the lowest cloud cover, it can also represent conditions at the peak of the dry season in the region. The data were obtained from the European Space Agency (ESA) through the Copernicus Open Access Hub (https://scihub.copernicus.eu/).

Sentinel-2 is the twin satellites (Sentinel-2A and Sentinel-2B) which carries an optical instrument payload of a Multi Spectral Instrument (MSI). Sentinel-2 MSI consists of 13 spectral bands from the visible, NIR, to the SWIR. The spatial resolution of Sentinel-2 MSI varies from 10 m to 60 m (Table 2-1). The images have a 290 km field of view (ESA, 2015).

Table 2-1: Sentinel-2 spectral characteristics (source: ESA, 2013)

Channel	Central wavelength (nm)	Bandwidth (nm)	Spatial Resolution (m)
1	443	20	60
2	490	65	10
3	560	35	10
4	665	30	10
5	705	15	20
6	740	15	20
7	783	20	20
8	842	115	10
8A	865	20	20
9	945	20	60
10	1.375	30	60
11	1.610	90	20
12	2.190	180	20

Figure 2-1: Location of the study area in the lowland region of Bekasi-Karawang, West Java Province. Map source: https://maps.google.com/

2.2 Methods

2.2.1 Sentinel-2 MSI Data Pre-processing

Sentinel-2 MSI L1C are already given in Top Of Atmosphere (TOA) Reflectance, scaled prior to output, and which can be changed to TOA reflectance with a simple calculation using the quantification value given within the metadata (ESA, 2015). Equation 2-1 is the conversion formula to convert the digital numbers (DN) to obtain physical values (ESA, 2015):

$$\text{Reflectance (float)} = \text{DC} / (\text{QUANTIFICATION\_VALUE}) \quad (2\text{-}1)$$

Atmospheric correction was then made using the Dark Object Subtraction (DOS) method (Chavez, 1988; Chavez, 1989).

2.2.2. Water Index Extraction

Several water indices ($NDWI_{Gao}$, $NDWI_{McFeeters}$, $NDWI_{Roger\& \ Kearney}$, and $MNDWI_{Xu}$) were extracted from the callibrated data using the following formulas:

$$NDWI_{Gao} = \frac{\rho 0.842 - \rho 1.610}{\rho 0.842 + \rho 1.610} \quad (2\text{-}2)$$

$$NDWI_{McFeeters} = \frac{\rho 0.560 - \rho 0.842}{\rho 0.560 + \rho 0.842} \quad (2\text{-}3)$$

$$NDWI_{Roger\& \ Kearney} = \frac{\rho 0.665 - \rho 2.190}{\rho 0.665 + \rho 2.190} \quad (2\text{-}4)$$

$$MNDWI_{Xu} = \frac{\rho 0.560 - \rho 2.190}{\rho 0.560 + \rho 2.190} \quad (2\text{-}5)$$

2.2.3 Comparison of the Detection Results and Determination of the Most Appropriate Model

Comparison of the detection results and determination of the most appropriate model were made by visually comparing the results of the application of the model with the original appearance of the surface water objects on the RGB image. In this case, a group of water objects was selected, which were considered sufficiently representative of surface water objects, such as lakes, dams, and ponds (see Figure 3-3).

3 RESULTS AND DISCUSSION

3.1 Water Index Extraction of Surface Water Objects from Sentinel-2

Surface water objects in the region can be identified visually from Sentinel-2 composite false color RGB 11-8-4 as shown in Figure 3-1. From the image, water is indicated by blue and dark colours, vegetation is indicated in green, and built-up objects in red. Dark colours represent clear water or water with low sediment content, whereas blue represents shallow or dirty water with a high sediment content.

Several water indices ($NDWI_{Gao}$, $NDWI_{McFeeters}$, $NDWI_{Roger\& \ Kearney}$, and $MNDWI_{Xu}$) were extracted from the surface water area from Sentinel-2 MSI using Equations 2-2 to 2-5. The results can be seen in Figure 3-2. In order to highlight the water object and to make it easier to compare the results from applying the water index model, we chose a NDWI value range of -0.5 to 0.5.

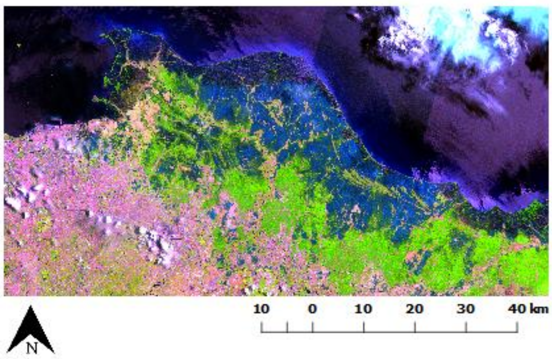


Figure 3-1: Spread of surface water area spatial distribution visually detected from Sentinel-2 MSI (acquisition date 21 September 2020)

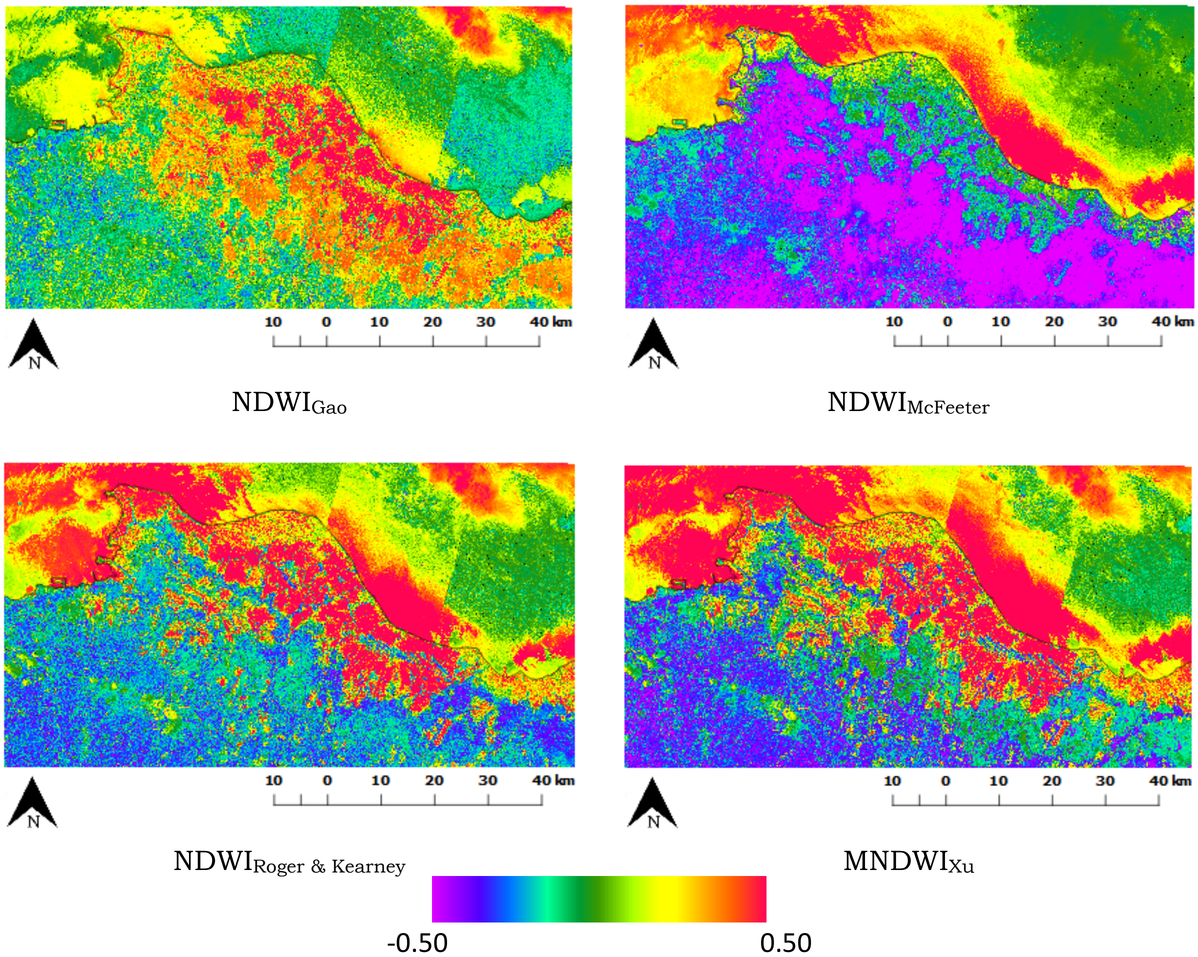
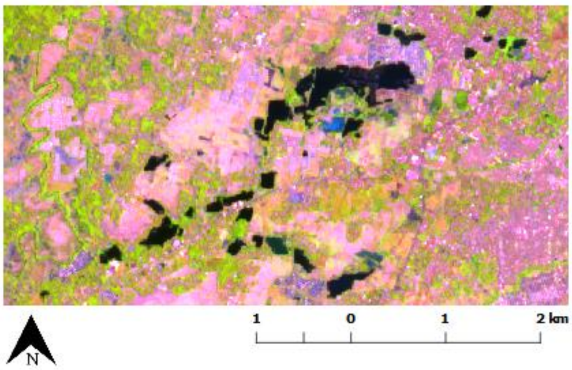
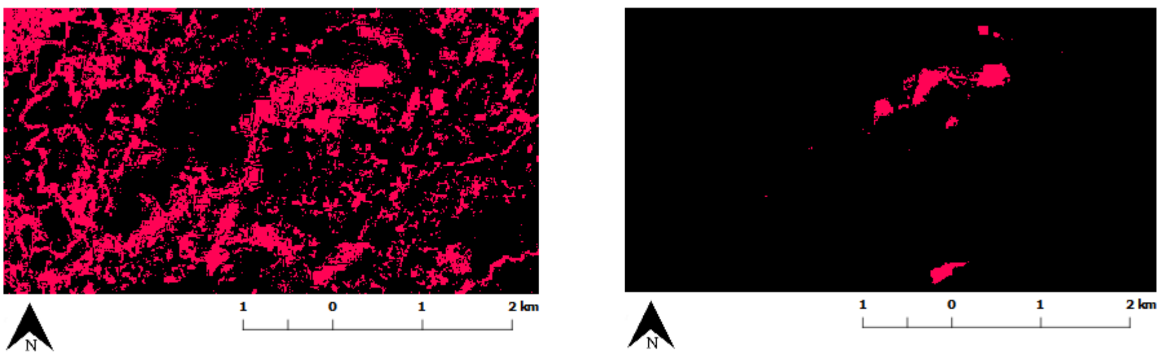


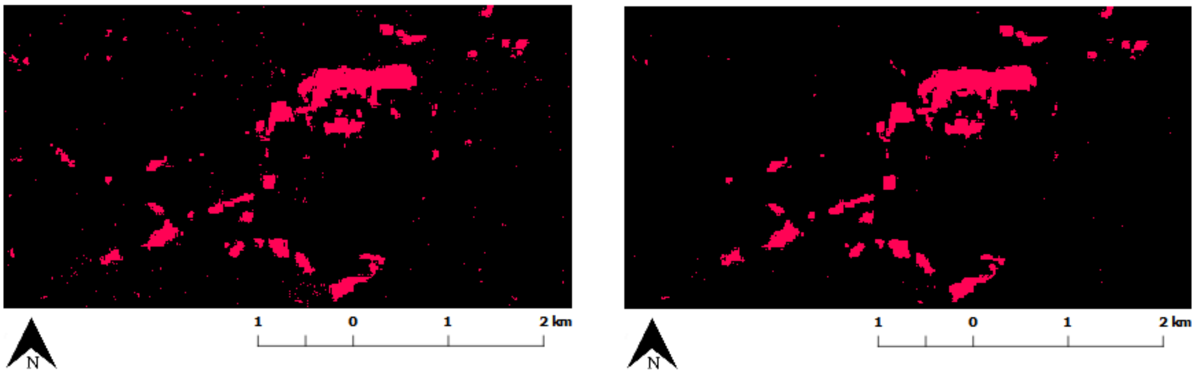
Figure 3-2: Water indices extracted from the surface water area from Sentinel-2 MSI. The coverage area is the same as in Fig. 3-1



(a) RGB 11-8-4



(b) SWA$_{Gao}$ (NDWI$_{Gao}$ > 0) (c) SWA$_{McFeeters}$ (McNDWI$_{McFeeters}$ > 0)



(d) $SWA_{Roger \& Kearney}$ ($NDWI_{Roger \& Kearney}$ > 0) (e) SWA_{Xu} ($MNDWI_{Xu}$> 0)

Figure 3-3: Surface water areas extracted (shown in red) based on water indices ($NDWI_{Gao}$, $NDWI_{McFeeters}$, $NDWI_{Roger\& Kearney}$, and $MNDWI_{Xu}$), with the NDWI value > 0.

3.2 Surface Water Areas (SWA) Detected from Water Indices

Surface water areas were extracted from several water indices ($NDWI_{Gao}$, $NDWI_{McFeeters}$, $NDWI_{Roger\& Kearney}$, and $MNDWI_{Xu}$). The results can be seen in Figure 3-3. Compared with the water object appearance detected visually from colour composite images in natural colour, RGB 11-8-4, it can be seen that the surface water areas extracted using $MNDWI_{Xu}$ (SWA_{Xu}) showed the best results. SWA_{Gao} gives results with very high commission errors. $SWA_{McFeeters}$ gave results with acceptable omission errors, whereas $SWA_{Roger\& Kearney}$ gave results with decent commission errors. Figure 3-4 shows the spatial distribution of surface water objects in the research location processed using the Xu (2006) method. Based on the results, it can be seen that during the dry season there are in fact many surface water sources, which are dominated by water in paddy fields and in swamps in the lowlands of the coastal area. The presence of abundant SWA in paddy fields and fishponds is because they are supplied from irrigation canals and from sea water. However, in the southern lowlands, which lead to the slopes of the foothills, it is rare to find SWA. Therefore, the SWA extraction results need to be filtered with paddy field and fishpond features. We took the two layers from the land cover map sourced from the Ministry of Environment and Forestry (see Figure 3-4).

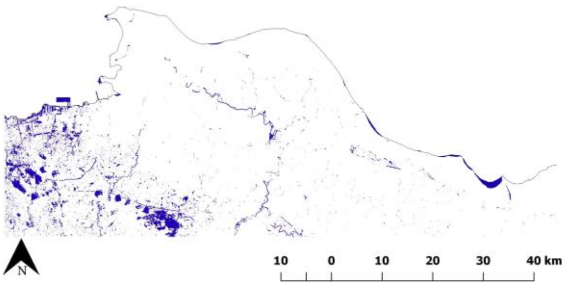


Figure 3-4: Spatial distribution of surface water areas (shown in blue) in the research location, processed using the Xu (2006) method.

3.3 Ground Check for Validation

Validation is performed by comparing the results from images with reference data from field checks on surface water objects. The checks were made in November - December 2020 (Figure 3-5). In these, several points and locations were identified which were considered representative of surface water objects such as lakes, dams, swamps, rivers, marshes and ponds. The majority of the check results confirm the detection results from the images.

(a) Object SWA: Marsh
Position: 107.078932 E / 6.194202 S

(b) Object SWA: Swamp
Position: 107.491739 E / 6.172442 S

(c) Object SWA: Pond
Position: 107.504117 E / 6.161895 S

Figure 3-5: Points and locations of surface water objects from the field check

4 CONCLUSION

The results conclude that the NDWI of Xu (2006), known as MNDWI, derived from Sentinel-2 MSI shows the best result in detecting surface water areas in lowland region of Bekasi-Karawang. During the dry season there are in fact many surface water sources, which are dominated by water in paddy fields and in swamps in the lowlands of the coastal area. The natural water sources (swamps, marshes, ponds) that still exist in the dry season can be used as alternative sources of water. Further research is still needed, based on different geographical conditions and in other regions of Indonesia.

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AUTHOR CONTRIBUTIONS

JTN and S are the main contributor. JTN; conceptualization, methodology and analysis: S; data processing, validating and analysis: GAC, AJ and JM; preparation of original draft and formal analysis: SH, AS and SS; writing and editing.

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