DETECTING THE SURFACE WATER AREA IN CIRATA DAM UPSTREAM CITARUM USING A WATER INDEX FROM SENTINEL-2

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Abstract. This paper describes the detection of the surface water area in Cirata dam, upstream Citarum, using a water index derived from Sentinel-2. MSI Level 1C (MSIL1C) data from 16 November 2018 were extracted into a water index such as the NDWI (Normalized Difference Water Index) model of Gao (1996), McFeeters (1996), Roger and Kearney (2004), and Xu (2006). Water index were analyzed based on the presence of several objects (water, vegetation, soil, and built-up). The research resulted in the ability of each water index to separate water and non-water objects. The results conclude that the NDWI of McFeeters (1996) derived from Sentinel-2 MSI showed the best results in detecting the surface water area of the reservoir.

Keywords: *Surface water area, NDWI, Sentinel-2, Cirata dam, Upstream Citarum*

1   INTRODUCTION

Remote sensing technology has long been utilised in water assessment and coastal management (Xu, 2006). These applications have involved the identification of water surfaces and other matters related to the object, such as floods and soil moisture.

Optical sensors capable of acquiring visible and near infrared wavelengths are essential for monitoring the objects and other phenomena. The Normalized Difference Water Index (NDWI), an index measured using Near Infrared (NIR) 0.86 μm and Short Wave Infra Red (SWIR) 1.24 μm, was first proposed by Gao (1996) to detect the liquid water content of vegetation canopies.

The NDWI of Gao is calculated as follows:

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

where $\rho 0.86$ μm is the reflectance value of the NIR 0.86 μm band, and $\rho 1.24$ is that of the SWIR 1.24 μm band.

NDWI was later developed to delineate surface water features and enhance their presence in remotely-sensed digital imagery (McFeeters, 1996). The NDWI of McFeeters is calculated as follows:

$$NDWI = \frac{\rho Green - \rho NIR}{\rho Green + \rho NIR} \quad (1\text{-}2)$$

where $\rho Green$ is the reflectance value of the green channel, and ρNIR is that of NIR channel.

In spite of the fact that McFeeters' and Gao's NDWIs employ the same terminology, the concepts of the two NDWIs are totally distinctive. Gao's NDWI is measured as the normalized difference between the NIR and SWIR wavelengths. Other researchers, Rogers and Kearney (2004),

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preferred red and SWIR bands (channels 3 and 5 of Landsat TM) to generate NDWI, as follows:

$$NDWI = \frac{\rho Red - \rho SWIR}{\rho Red + \rho SWIR} \qquad (1\text{-}3)$$

Xu (2006) found that McFeeters' NDWI was incapable of totally separating built-up objects from water objects. The modification of the NDWI by employing a MIR channel instead of an NIR band can substantially improve the enhancement of open water objects, and can rapidly and precisely segregate water from non-water objects. To compensate for this disadvantage of McFeeters' NDWI, Xu (2006) proposed a modified NDWI (MNDWI), in which the SWIR band was utilised to replace the NIR channel in McFeeter's NDWI formula:

$$MNDWI = \frac{\rho Green - \rho SWIR}{\rho Green + \rho SWIR} \qquad (1\text{-}4)$$

Ding (2009) developed the new water index (NWI) using four spectral bands from blue to the MIR region. In this new index, the green band was replaced by the blue band, and the NIR band was replaced by the total reflectance from three infrared bands in Landsat TM imagery. The index is measured as follows:

$$NWI = \frac{\rho Blue - (\rho NIR + \rho SWIR1 + \rho SWIR2)}{\rho Blue + (\rho NIR + \rho SWIR1 + \rho SWIR2)} \qquad (1\text{-}5)$$

where ρBlue is the reflectance on the blue band, corresponding to Band 1 in TM imagery. SWIR1 and SWIR2 are two SWIRs, corresponding to Bands 5 and 7 in TM imagery respectively.

Several studies have showed that the normalized difference water index (NDWI) has been successfully used to delineate surface water features better than other indices. Wang et al. (2017) succesfully applied the normalized

difference water index (NDWI) and the modified normalized difference water index (MNDWI) to Landsat time-series images during the period 1976–2015 to discriminate surface water and land features in order to understand the spatio-temporal changes of the Ningbo coastline.

Du et al. (2012), who conducted research on estimating surface water area changes using time-series Landsat data in the Qingjiang River Basin, China, found that NDWI and MNDWI could extract surface water areas from Landsat data and could also be used to monitor surface water dynamic changes and detect flood disasters.

Spectral water indices, such as the normalized difference water index (NDWI) (McFeeters, 1996) and modified NDWI (MNDWI) (Xu, 2006), can extract water body information more accurately, quickly and easily than supervised/unsupervised classification methods (Li et al., 2013). Szabo et al. (2016) found that water-related indices (NDWI, MNDWI) were more effective in enhancing water features.

Acharya et al. (2016) compared the NDVI, NDWI and MNDWI to detect the changes in lakes in Pokhara, Nepal using Landsat data. Their results show the NDWI gave better results than NDVI and MNDWI. In addition, Ashraf et al. (2015) conducted change detection analysis using the NDVI, NDWI, MNDWI and NDMI (Normalized Difference Moisture Index) from Landsat multitemporal data (Landsat-2, Landsat-4, Landsat-5, Landsat-7 and Landsat-8), and showed that NDWI performed better than the other indices in all the related base years and also had the best accuracy with the ground.

Until now, water surface identification and mapping based on water indices has been dominated by the use of optical images from Landsat TM,

ETM+ and OLI data. However, ESA's newest generation of medium-resolution optical satellites, Sentinel-2, are now available.

Sentinel-2 is a European wide swath, high resolution, multispectral imaging mission. The twin satellites of Sentinel-2 (Sentinel-2A and Sentinel-2B) will provide continuity of SPOT and Landsat-type image data (ESA, 2015). Sentinel-2 carries an optical instrument payload of a Multi Spectral Instrument (MSI), consisting of 13 spectral bands spanning from the visible, to the near infrared, and to the short wave infrared. The spatial resolution varies from 10 m to 60 m, depending on the spectral band, with a 290 km field of view. This unique combination of high spatial resolution, wide field of view and spectral coverage will represent a major step forward compared to current multi-spectral missions. The mission foresees a series of satellites, each having a 7.25-year lifetime over a 15-year period, starting with the launch of Sentinel-2A in 2013. Sentinel-2 will directly contribute to the land monitoring, emergency response, and security services (Drusch et al., 2012).

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

Band number	Central wavelength (μm)	Bandwidth (nm)	Resolution (m)
1	0.443	20	60
2	0.490	65	10
3	0.560	35	10
4	0.665	30	10
5	0.705	15	20
6	0.740	15	20
7	0.783	20	20
8	0.842	115	10
8A	0.865	20	20
9	0.945	20	60
10	1.375	30	60
11	1.610	90	20
12	2.190	180	20

Sentinel-2 data are acquired on 13 spectral bands in the VNIR and SWIR, with four bands at 10 m: 490 nm (B2), 560 nm (B3), 665 nm (B4), 842 nm (B8); six bands at 20 m: 705 nm (B5), 740 nm (B6), 783 nm (B7), 865 nm (B8A), 1 610 nm (B11), 2 190 nm (B12); and three bands at 60 m: 443 nm (B1), 945 nm (B9) and 1.375 nm (B10) (ESA, 2015) (Table 1-1).

Figure 1-1: Location of the study area, Cirata dam, a large reservoir located on upstream Citarum, West Java Province. Map source: http://landsat-catalog.lapan.go.id

Considering the spectral and spatial characteristics of the MSI Sentinel-2, it is clear that these imagery data have the potential to be used in the identification and mapping of water surface areas.

This research was conducted to attempt to use the MSI Sentinel-2 imagery to identify surface water areas using several water indices in regions in Indonesia. The chosen location was the Cirata dam, a large reservoir located on upstream Citarum, West Java Province (Figure 1-1).

2 MATERIALS AND METHODOLOGY
2.1 Data

Sentinel-2 MSI Level 1C (MSIL1C) data were used in this research. Their acquisition date was 16 November 2018, with a coverage of around 106:48:27.51E / 6:19:45.67S (Top Left) - 107:48:19.24E / 7:19:1.24S (Bottom Left). This coverage covers most regions of upstream Citarum. The data were obtained from the European Space Agency (ESA) through the Copernicus Open Access Hub.

The Sentinel-2 MSI Level-1C (MSIL1C) has ortho-rectified and UTM geocoded Top-of-Atmosphere Reflectance with sub-pixel multispectral and multi-date registration. The tile covers a 100x100km UTM tile covered within one orbit (ESA, 2015). The MSIL1C tile consists of a Level-1C_Tile_Metadata_File (Tile Metadata); an XML main metadata file (DIMAP mandatory file) containing the requested level of information and referring to all the product elements describing the tile; an IMG_DATA folder containing image data files compressed using the JPEG2000 algorithm, one file per band; a QI_DATA folder containing QLQC XML reports of quality checks, mask files and PVI files; an Inventory_Metadata.xml: inventory metadata file (mandatory); a

manifest.safe: XML SAFE manifest file (mandatory); and a rep-info: folder containing the XSD schema provided inside a SAFE Level-0 granule (ESA, 2015).

2.2 Methods
2.2.1 Sentinel-2 MSI Data Pre-processing

MSIL1C are already provided in the Top of Atmosphere (TOA) Reflectance, scaled prior to output, which can be converted to TOA reflectance by a simple calculation using the quantification value provided in the metadata (ESA, 2015).

The conversion formula to apply to image digital numbers (DNs) to obtain physical values is (ESA, 2015):

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

Furthermore, atmospheric correction was made by the DOS (Dark Object Subtraction) method (Chavez, 1988; Chavez, 1989).

2.2.2 Water Index Extraction

Several water indices were extracted from the calibrated data resulting from the pre-processing. Taking into account the spectral characteristics of the Sentinel-2 MSI channels, the water indices were extracted using following equations:

$$\text{NDWI}_{\text{Gao}} = \frac{\rho0.842 - \rho1.610}{\rho0.842 + \rho1.610} \tag{2-2}$$

$$\text{NDWI}_{\text{McFeeters}} = \frac{\rho0.560 - \rho0.842}{\rho0.560 + \rho0.842} \tag{2-3}$$

$$\text{NDWI}_{\text{Roger\& Kearney}} = \frac{\rho0.665 - \rho2.190}{\rho0.665 + \rho2.190} \tag{2-4}$$

$$\text{MNDWI}_{\text{Xu}} = \frac{\rho0.560 - \rho2.190}{\rho0.560 + \rho2.190} \tag{2-5}$$

3   RESULTS AND DISCUSSION

Figure 3-1 shows the water index extracted from Sentinel-2 MSI in Cirata dam. In the figure, the water surface area can be detected from several water indices. Compared with the colour composite image in natural colours, RGB 11-8-4 (Figure 3-2), and taking into account the results using and comparing various water-based indices, it can generally be seen that, among the NDWI models, but Gao's, are appropriate for detecting surface water areas. However, when examined in more detail, it can be seen that the NDWI of McFeeters (1996) shows the best results in detecting the surface water area.

Previous studies have attempted to use such imagery data for the identification and mapping of water surface areas and have obtained different results. Kwang et al. (2018) attempted to compare Landsat 8 and Sentinel 2A using water extraction indexes along the Volta River. Their results show that the modified normalized water difference index (MNDWI$_{Xu}$) proved to be the universal water body enhancement index because of its performance with both the Landsat 8 and Sentinel 2A images.

The modified normalized water difference index can therefore be recommended for use with either Landsat 8 or Sentinel 2A over other water indexes such as the normalized water difference index and the automatic water extraction index. Du et al. (2006) also attempted using Sentinel-2 imagery for mapping with the modified normalized difference water index, and their results show that MNDWI$_{Xu}$ can enhance water bodies and suppress built-up features more efficiently than NDWI. However, research conducted by Sekertekin et al. (2018) on identifying surface water resources in Çatalan and Yedigöze dam reservoirs in Turkey using

Sentinel-2 found that NDWI$_{McFeeters}$ produced slightly more accurate results than MNDWI$_{Xu}$.

In another study, Yang et al. (2017) performed mapping of urban surface water bodies using Sentinel-2 MSI in Beijing, which is located inland, and Yantai, which is located in a coastal area. Their results show that the NDWI-based MNDWI$_{Xu}$ images exhibit higher separability and are more effective for both classification-level and boundary-level final water maps than traditional approaches.

Research conducted in Indonesia by Yulianto et al. (2018), who attempted to observe inundated areas using Landsat-8 multitemporal images in Bandung basin, found that MNDWI was the most appropriate parameter to use to detect flooded areas in the Bandung basin which had heterogeneous land surface conditions. In other studies, by using Landsat-7 ETM+ image data, the extent of inundated areas caused by floods in lowland regions could be identified and separated based on NDWI, MNDWI, and NWI. However, the NDWI method of McFeeters (1996) provided more appropriate results when compared to the other three methods (Suwarsono et al., 2013). These different results are most likely due to the influence of water environment characteristic on which model produces the more accurate results.

However, in principle, the NDWI of McFeeters utilises reflected near-infrared radiation and visible green light to enhance the presence of features, while eliminating the presence of soil and terrestrial vegetation. The NDWI of McFeeters may moreover provide analysts with turbidity estimations of water bodies utilising remote sensing data (McFeeters, 1996). The band selection of McFeeters's NDWI was chosen to maximise the typical

reflectance of water features by using the green light channel, to minimise the low reflectance of NIR by water objects, and to take advantage of the high reflectance of NIR by terrestrial vegetation and soil (McFeeters, 1996).
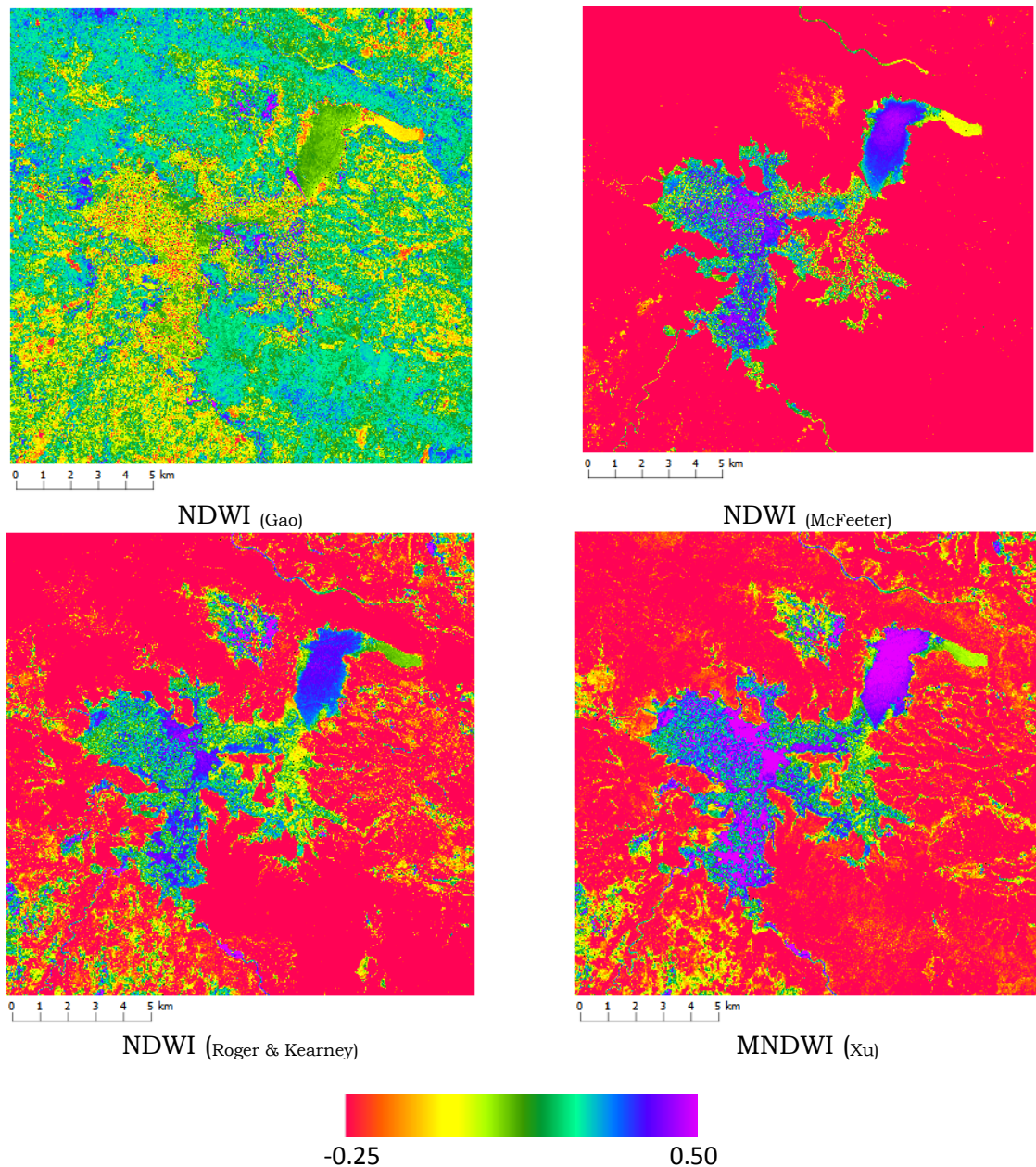

NDWI (Gao)

NDWI (McFeeter)

NDWI (Roger & Kearney)

MNDWI (Xu)

-0.25   0.50

Figure 3-1: Water indices extracted from Sentinel-2 MSI.

4   CONCLUSION

The results conclude that the NDWI of McFeeters (1996) derived from Sentinel-2 MSI produces the best results in detecting the surface water area of the reservoir compared to other water indices. This model was conducted to maximize the typical reflectance of water features by using a green light channel, to minimize the low reflectance of NIR by water objects, and to take advantage of the high reflectance of NIR by terrestrial vegetation and soil. However, applications using Sentinel-2 MSI imagery for other regions that have different water environment conditions probably give different results. Therefore, further research is still

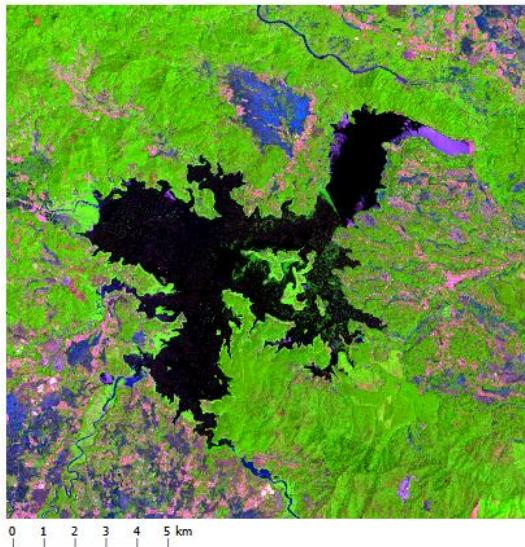needed for different water environment conditions of other regions in Indonesia.

Figure 3-2: Sentinel-2 MSI natural colour composite (RGB 11-8-4).

AUTHOR CONTRIBUTIONS

Detecting The Surface Water Area In Cirata Dam Upstream Citarum Using A Water Index From Sentinel-2. Lead Author: Suwarsono and Fajar Yulianto, Co-Author: Hana Listi Fitriana, Udhi Catur Nugroho, Kusumaning Ayu Dyah Sukowati, and Muhammad Rokhis Khomarudin.

REFERENCES

Acharya, T.D., Yang, I.T., Subedi, A. et al. (2016). Change detection of lakes in Pokhara, Nepal using Landsat data. *Proceedings 1*(17), doi:10.3390/ecsa-3-E005.

Ashraf, M., & Nawaz, R. (2015). A Comparison of Change Detection Analyses Using Different Band Algebras for Baraila Wetland with Nasa's Multi-Temporal Landsat Dataset. *Journal of Geographic Information System, 17*,1-19.

Chavez, Jr. P.S. (1988). An improved dark-object subtraction technique for atmospheric scattering correction of multispectral data. *Remote Sensing of Environment 24*, 459–79.

Chavez, Jr. P.S. (1989). Radiometric Calibration of Landsat Thematic Mapper Mutispectral Images. *Photogrammetric Engineering and Remote Sensing, 55*(9),1285-1294.

Ding, F. (2009). A New Method for Fast Information Extraction of Water Bodies Using Remotely Sensed Data. *Remote Sensing Technology and Application, 24*(2), 167–171.

Drusch, M., Del Bello, U., Carlier, S. et al., (2012). Sentinel-2: ESA's Optical High-Resolution Mission for GMES Operational Services. *Remote Sensing of Environment 120*, 25-36.

Du, Z., Linghu, B., Ling, F. et al. (2012). Estimating surface water area changes using time-series Landsat data in the Qingjiang River Basin, China, *Journal of Applied Remote Sensing, 6*(1), 063609.

Du, Y., Zhang, Y., Ling, F. et al. (2016). Water Bodies' Mapping from Sentinel-2 Imagery with Modified Normalized Difference Water Index at 10-m Spatial Resolution Produced by Sharpening the SWIR Band. *Remote Sensing 8*(4),

354; https://doi.org/10.3390/rs804035 4

ESA (2013). Sentinel 2, The Operational Copernicus Optical High Resolution Land Mission. Https://www.esa.int/ copernicus.

ESA (2015). Sentinel-2 Products Specification Document. Ref : S2-PDGS-TAS-DI-PSD, Issue : 13.1, Date : 18/11/2015. Https://sentinel.esa.int/web/sentinel/user-guides/document-library.

Feng, D. (2009). A new method for fast information extraction of water bodies using remotely sensed data. *Remote Sensing Technology and Application, 24*(2), http:// www.oalib.com/ paper/1468694#.XgQY7EczZ1s.

Gao, B.C. (1996). NDWI a normalized difference water index for remote sensing of vegetation liquid water from Space. *Remote Sensing of Environment, 58*, 257-266.

Kwang, C., Osei Jr, E.M., & Amoah, A.S. (2018). Comparing of Landsat 8 and Sentinel 2A using Water Extraction Indexes over Volta River. *Journal of Geography and Geology, 10*(1), doi:10.5539/jgg.v10n1p1.

Li, W., Du, Z., Ling, F. et al. (2013). A Comparison of Land Surface Water Mapping Using the Normalized Difference Water Index from TM, ETM+ and ALI. *Remote Sensing 5*(11), 5530–5549. doi:10.3390/rs5115530.

Li, P., Jiang, L., & Feng, (2014). Cross-Comparison of Vegetation Indices Derived from Landsat-7 Enhanced Thematic Mapper Plus (ETM+) and Landsat-8 Operational Land Imager (OLI) Sensors., *Remote Sensing, 6*, :310-329., DOI:10.3390/ rs6010310

McFeeters, S.K. (1996). The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. *International Journal of Remote Sensing 17*(7), 1425-1432. DOI: 10.1080/ 01431169608948714.

Rogers, A.S., & Kearney, M.S. (2004). Reducing Signature Variability in Unmixing Coastal Marsh Thematic Mapper Scenes Using Spectral Indices. *International Journal of Remote Sensing 25*(12), 2317–2335.

Sekertekin, A., Cicekli, S.Y., & Arslan, N. (2018). Index-Based Identification of Surface Water Resources Using Sentinel-2 Satellite Imagery. *2018 2nd International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT)*, Ankara, 2018, pp. 1-5, doi: 10.1109/ISMSIT.2018.8567062.

Suwarsono, Nugroho, J.T., & Wiweka. (2013). Identification of Inundated Area Using Normalized Difference Water Index (NDWI) on lowland region of Java Island. *International Journal of Remote Sensing and Earth Sciences, 10*(2), 114-121.

Szabó, S., Gácsi, Z., & Balász, B.B. (2016). Specific features of NDVI, NDWI and MNDWI as reflected in land cover categories. *Landscape & Environment, 10*(3-4), 194-202.

Wang, X., Liu, Y., Ling, F. et al. (2017). Spatio-Temporal Change Detection of Ningbo Coastline Using Landsat Time-Series Images during 1976–2015. *International Journal of Geo-Information, 6*(68), doi:10.3390 /ijgi6030068.

Xu, H. (2006). Modification of normalised difference water index (NDWI) to enhance open water features in remotely sensed imagery. *International Journal of Remote Sensing 27*(14), 3025–3033.

Yang J., & Du, X. (2017). An enhanced water index in extracting water bodies from Landsat TM imagery. *Annals of GIS, 23*(3), 141-148. DOI:10.1080/ 19475683.2017.1340339.

Yulianto, F., Suwarsono, Sulma, S. et al. (2018). Observing the inundated area using Landsat-8 multitemporal images and determination of flood-prone area in Bandung basin. *International Journal of Remote Sensing and Earth Sciences, 15*(2), 131-14