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OBSERVING THE INUNDATED AREA USING LANDSAT-8 MULTITEMPORAL IMAGES AND DETERMINATION OF FLOOD-PRONE AREA IN BANDUNG BASIN

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Abstract. Flood is the most frequent hydro-meteorological disaster in Indonesia. Flood disasters in the Bandung basin result from increasing population density, especially in the Citarum riverbank area, accompanied by land use changes in upstream of the Citarum catchment area which has disrupted the river's function. One of the basic issues that need to be investigated is which areas of the Bandung basin are prone to flooding. This study offers an effective and efficient method of mapping flood-prone areas based on flood events that have occurred in the past through the use of historical remote sensing image data. In this research, Landsat-8 imagery was used to observe the inundated area in the Bandung basin in the past (2014–2018) using an improved algorithm, the modified normalized water index (MNDWI). The results of the study show that MNDWI is the appropriate parameter to be used to detect flooded areas in the Bandung basin area that have heterogeneous land surface conditions. The flood-prone area was determined based on flood events for 2014 to 2018, identified as inundated areas in the images. The estimation of the flood-prone area in the Bandung basin is 11,886.87 ha. Most of the flood-prone areas are in the subdistricts of Rancaekek, Bojongsoang, Solokan Jeruk, Ciparay, Cileunyi, Bale Endah and Cikancung. This area geographically or naturally is a water habitat area. Therefore, if the area will be used for residential, this will have consequences that flood will always be a threat to the area.

Keywords: *inundated area, flood-prone area, Bandung basin, Landsat-8, MNDWI*

1 INTRODUCTION

Flood is an overflow of river water caused by river discharge that exceeds the capacity of river channels in high rainfall conditions, or inundation that occurs in certain areas which are usually not stagnant (Kodoatie & Sugiyanto 2002). Flood is the most frequent hydro-meteorological disaster in Indonesia, especially in Java, and is often associated with deforestation in the upstream area of the watershed system (Harliani 2014). Flood disasters in the Citarum watershed often occur in its upper part, which comprises the Bandung basin area. The main problem that causes flooding in the Bandung basin is the increasing population pressure and economic activity which has caused land use changes (Wangsaatmaja *et al.* 2006). Floods in the Bandung area cause economic and social losses. Such disasters occur when rainfall is high, and the water volume exceeds the capacity of the Citarum watershed (Darwin *et al.* 2018).

One of the basic issues that need to be investigated is which areas of the Bandung basin are prone to flooding. Understanding natural hazards is an important aspect for city planning and the implementations of policy and development. Understanding and awareness of the hazards will help improve planning for future city development (Raharjo 2017).

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Almost all of the hazard and disaster data collected in the past presents many difficulties for analysis. This study offers an effective and efficient method of mapping flood-prone areas based on flood events that have occurred in the past by utilizing remote sensing image data.

Remote sensing shows important capabilities in mapping surface water objects and monitoring these dynamics. The design of the spectral water index is based on the fact that water objects will absorb energy at near-infrared (NIR) and short-wave (SWIR) wavelengths. The normalized water difference index (NDWI) has been used successfully to describe surface water features (Ji *et al.* 2009).

Gao (1996) developed an NDWI used for estimating water content of vegetation canopy. Gao's NDWI is calculated as the normalized difference of NIR and SWIR bands. Unlike Gao (1996), Rogers and Kearney (2004) used red and SWIR bands (bands 3 and 5 in Landsat TM) to produce NDWI. McFeeters (1996) developed the normalized difference water index (NDWI) based on Green and NIR channel. The NDWI value ranges from -1 to 1. McFeeters (1996) set zero as the threshold. Water is defined if NDWI>0 and it is non-water if NDWI <=0.

Furthermore, Xu (2006) found that McFeeters' NDWI was unable to completely separate built-up features from water features. NDWI showed positive values in built-up features which were similar to water because the NIR reflectance was lower than the green reflectance. Then, Xu (2006) proposed the modified NDWI (MNDWI), in which the SWIR band was used to replace the NIR band in McFeeters' NDWI formula. Same with McFeeters' NDWI, the threshold value for MNDWI was set to zero. By using this formula, it found a manual adjustment of the threshold could achieve a more accurate result in the water mapping (Xu 2006).

The MNDWI can enhance open water features while efficiently suppressing and even removing built-up land noise as well as vegetation and soil noise. The improved algorithm has improved the ability to sharpen surface water objects, and in the context of these parameters can reduce interference from building objects, vegetation, and soil and is therefore very appropriate to be used to detect water objects that are associated with such land cover (Xu 2006).

The Bandung basin area has varied land cover conditions, most of which are forests, plantations, settlements, and agriculture (Narulita *et al.* 2008). There has been a massive conversion of agricultural land and plantations into built-up land (Nuraeni *et al.* 2017). By considering the condition of varied and dynamic land cover, the MNDWI method from Xu (2006) is a suitable method for inundation area mapping in Bandung basin.

2 MATERIALS AND METHODOLOGY

2.1 Location and data

Referred to Dam *et al.* (1996), the greater Bandung area is a large intermontane basin surrounded by volcanic highlands. The central Bandung plain is surrounded by Late Tertiary and Quaternary volcanic. North of Bandung, the Sunda-Tangkuban Perahu volcanic complex is located. The adjacent Lembang plain is bordered to the south by the conspicuous Lembang fault. The Citarum River with its tributaries forms the main drainage system of the Bandung basin catchment. It meanders through the center of the basin in a western direction and, after crossing several topographical barriers through narrow gorges, reaches the northern coastal lowlands. Deposits in the basin comprise coarse volcanoclastic, fluvial sediments and notably a thick series of lacustrine deposits.

The research location is the part of the Bandung basin covered by Landsat-8 satellite path/row 122/065. The research sites are located in the Bandung City, Bandung Regency, and Sumedang Regency, West Java Province. Figure 2-1 shows the location of the study.

The data used are Landsat-8, path/row 122/065, with data acquisition times of:

- 9 June 2014
- 12 June 2015
- 6 January 2016
- 16 May 2017
- 6 July 2018

Landsat-8 data were obtained from the Remote Sensing Technology and Data Center of the Indonesian National Institute of Aeronautics and Space (LAPAN). The data format is GeoTIFF, and the level of the Landsat-8 data is the one terrain-corrected product (L1T). The L1T data is available to users as radiometric and geometrically corrected images. The level image is presented in units of Digital Numbers (DNs) which can be easily rescaled to spectral radiance or top of atmosphere (TOA) reflectance (Zanter 2015).

Table 2-1: OLI spectral and spatial specification (Irons *et al.* 2012)

Bands	**Bandwidth (µm)**	**GSD (m)**
1	0.433 – 0.453	30
2	0.450 – 0.515	30
3	0.525 – 0.600	30
4	0.630 – 0.680	30
5	0.845 – 0.885	30
6	1.560 – 1.660	30
7	2.100 – 2.300	30
8	0.500 – 0.680	15
9	1.360 – 1.390	30

The Landsat 8 satellite is the latest generation of the Landsat satellite series from the NASA and the United States of Geological Survey (USGS) - Department of the Interior. It has advantages over its predecessors (Landsat 1, Landsat 2, Landsat 3, Landsat 4, Landsat 5, Landsat 6 (failed to reach orbit) and Landsat 7), in that it carries a charge sensor (the Operational Land Imager or OLI) which consists of nine spectral channels with a spatial resolution of 30 m (15 m for the panchromatic channel) and a thermal infrared sensor (TIRS) which measures land-surface temperature in two thermal bands with a 100 m spatial resolution (Irons *et al.* 2012).

(a)

Figure 2-1: Location of the study area of Bandung basin (red rectangle), coverage of Landsat-8 for path/row 122/065 (green rectangle). Map source: http://landsat-catalog.lapan.go.id/

Table 2-2: TIRS spectral bands and spatial resolution (Irons *et al.* 2012)

Bands	Center wavelength (μm)	Minimum lower band edge (μm)
10	10.9	10.6
11	12.0	11.5

2.3 Methods

2.3.1 Radiometric correction

The radiometric correction includes converting the DN data into a TOA reflectance (Zanter 2015). Then, the atmospheric correction is done by the DOS (Dark Object Subtraction) model (Chavez 1988; Chavez 1989).

2.3.2 Extraction of the MNDWI pixels

In this research, the inundated area of the Bandung basin was analyzed using Landsat-8 images based on the modified normalized water index (MNDWI), as developed by Xu (2006). The MNDWI can be expressed as follows:

$$MNDWI = (\rho\text{Green}-\rho\text{MIR})/(\rho\text{Green}+\rho\text{MIR}) \quad (2\text{-}1)$$

Where ρMIR is the middle infrared reflectance value, and ρGreen is the green reflectance value. Then, by using Landsat 8 data, the formula can be written as follows:

$$MNDWI = (\rho 3-\rho 6) / (\rho 3+\rho 6) \quad (2\text{-}2)$$

Where $\rho 3$ is the reflectance value of band 3 and ρ6 is the reflectance value of band 6.

The obtained MNDWI images will show that water will have greater positive values than from the NDWI, built-up land will have negative values and soil and vegetation will also have negative values. So, the greater enhancement of water in the MNDWI image will result in more accurate extraction of open water features, because the built-up land, soil, and vegetation associated with them will have negative values (Xu 2006). Based on the MNDWI equation, the pixels of the inundated area can be extracted with the following logical expression:

$$\text{IF } MNDWI_{ij} > 0 \text{ THEN } IA_{ij} \quad (2\text{-}3)$$

Where $\rho MNDWI_{ij}$ is *MNDWI* value for specific row and column pixels. IA_{ij} is inundated area pixels for the specific rows and columns.

2.3.2 Flood-prone area determination

The flood-prone area was determined based on flood events for 2014 to 2018, identified as inundated areas in the images. Flood-prone areas (*FPA*), (as raster polygon) were determined as a union (U) of all raster polygons of inundated areas (*IA*) as follows:

$$FPA = IA_{t1} \text{ U } IA_{t2} \text{ U } IA_{t3} \text{ U } IA_{t4} \text{ U } IA_{t5} \quad (2\text{-}4)$$

Where IA_{t1}, IA_{t2}, IA_{t3}, IA_{t4}, and IA_{t5} are Pixels of Inundated Area derived from Landsat-8 date acquisition of 9 June 2014, 12 June 2015, 6 January 2016, 16 May 2017, and 6 July 2018 consecutively.

3 RESULTS AND DISCUSSION

3.1 Inundated areas identified visually from Landsat-8

Inundated areas can be identified visually from Landsat-8 composite false color RGB 654 images. In the images, water is indicated by bluish colours, vegetation by greenish colours and built-up objects by reddish colours. Figure 3-1 shows the inundated areas seen visually from Landsat-8 composite false color RGB 654 images of the Bandung basin. The events are for 9 June 2014, 12 June 2015, 6 January 2016, 16 May 2017 and 6 July 2018. Based on the description of some of these images, it can be seen that the most severe flooding occurred on 6 January 2016.

3.2 Inundated areas extracted from Landsat-8 imagery based on MNDWI

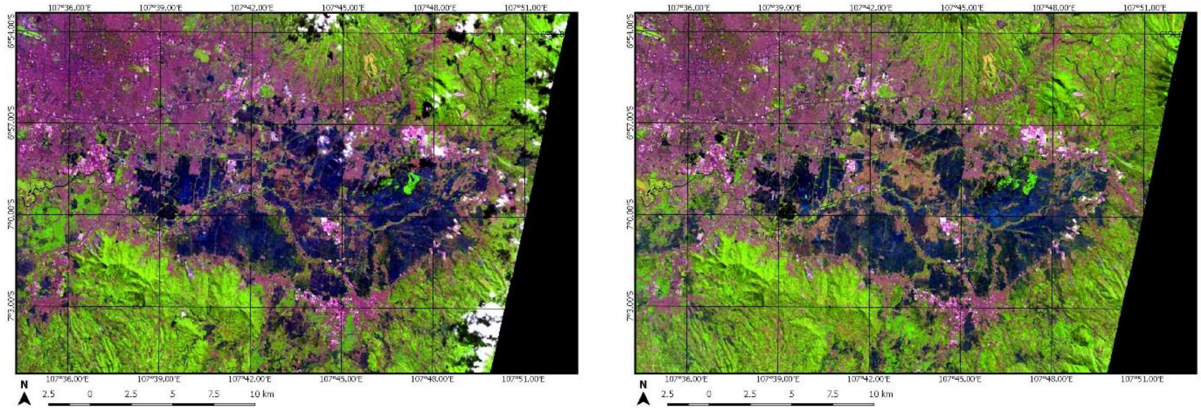
Inundated areas were extracted from Landsat-8 imagery based on the MNDWI parameter (Equations 2 and 3) for all images. The results (raster polygons of inundated areas) can be seen in Figure 3-2. The spread of the spatial distribution of the inundated area varies from year to year (Table 3-1). Based on the images, the most severe flooding, with an area of 11,116 hectares, occurred on 6 January 2016.

3.3 Determination of flood-prone area

Figure 3-5 shows the flood-prone area of the Bandung basin, the result of the union of several inundated area raster polygons. The estimation of the extent of flood-prone areas in the Bandung basin is 11,886.87 hectares. This area covers three districts: Bandung City, Bandung, and Sumedang. Most of the flood-prone areas are in the subdistricts of Rancaekek, Bojongsoang, Solokan Jeruk, Ciparay, Cileunyi, Bale Endah, and Cikancung. Based on spatial distribution and area, these six sub-districts were the most severely affected by the flood. When an outline is drawn which limits the flood-prone areas, it forms a kind of 'bowl'. Noting the topographic conditions, it can be seen that the bowl area is a concentration area of water flow originating from the north, south, west and east slopes. The area geographically or naturally is a water habitat area. Therefore, if the area will be used for residential, this will have consequences that flood will always be a threat to the area.

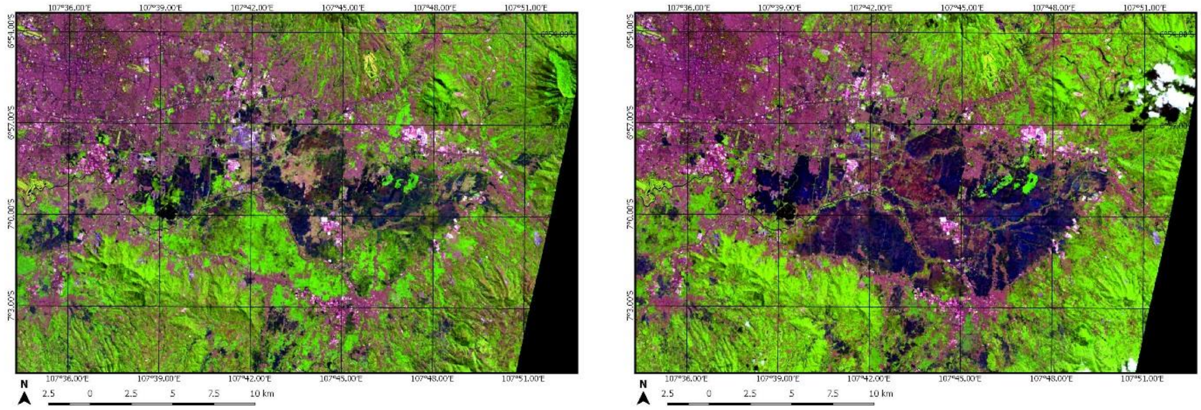
Table 3-1: The spread of inundated area spatial distribution

Date	Inundated areas (hectares)
9 June 2014	5,089
12 June 2015	4,772
6 January 2016	11,116
16 May 2017	3,822
6 July 2018	3,631



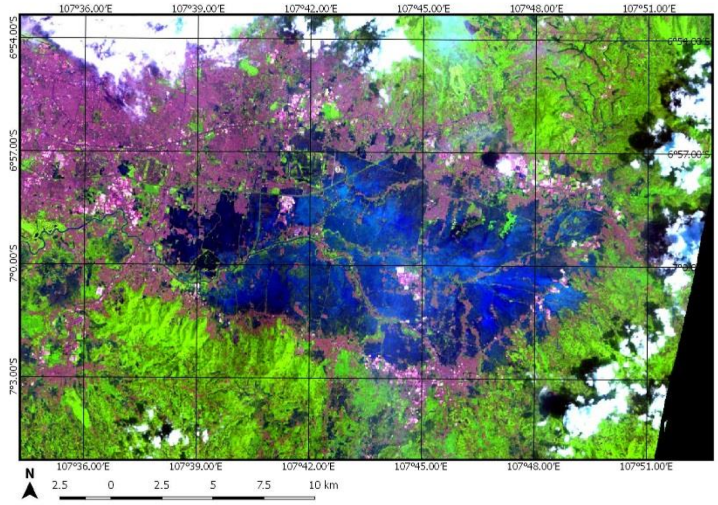
9 June 2014

12 June 2015



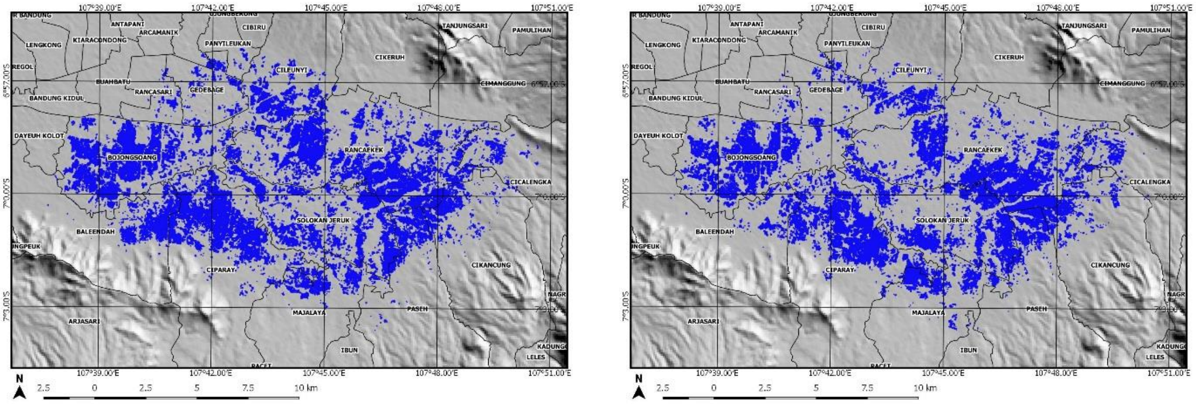
6 July 2018

16 May 2017



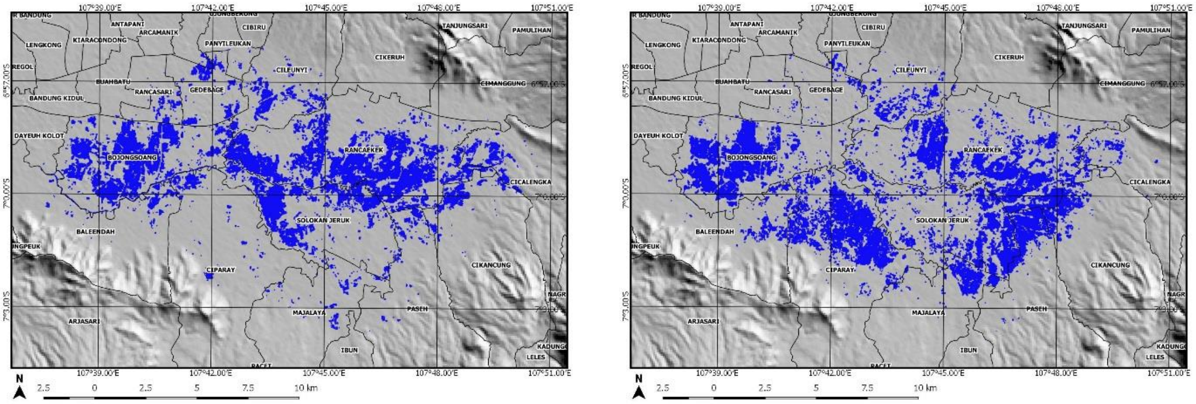
6 January 2016

Figure 3-1: Inundated areas (shown in blue) seen visually from Landsat-8 composite false color RGB 654 images of the Bandung basin



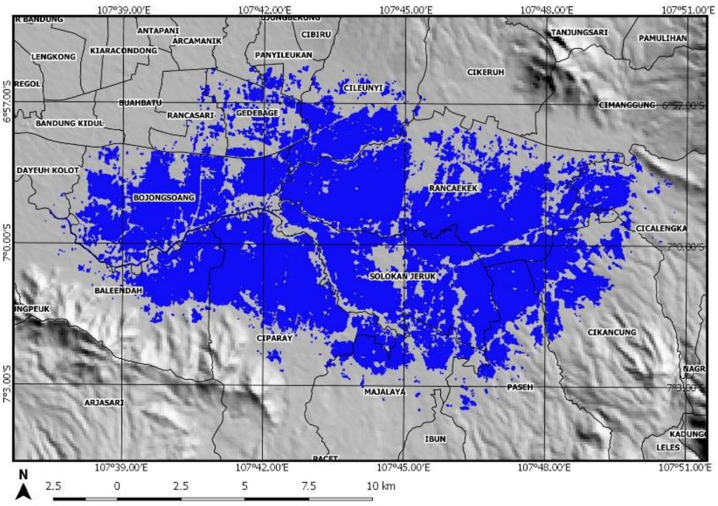
9 June 2014 (5,089 hectares)

12 June 2015 (4,772 hectares)



6 July 2018 (3,631 hectares)

16 May 2017 (3,822 hectares)



6 January 2016 (11,116 hectares)

Figure 3-2: Inundated areas of the Bandung basin (shown in blue) extracted from Landsat-8 images, based on MNDWI, were compiled above the SRTM30 DEM.

Table 3-2: Distribution of flood-prone areas based on administrative boundaries

Subdistrict	District	Area (ha)	Area %
Rancaekek	Bandung	2,944.04	24.77
Bojongsoang	Bandung	1,736.93	14.61
Solokan Jeruk	Bandung	1,723.37	14.50
Ciparay	Bandung	1,708.53	14.37
Cileunyi	Bandung	685.59	5.77
Bale Endah	Bandung	652.69	5.49
Cikancung	Bandung	633.40	5.33
Paseh	Bandung	547.73	4.61
Majalaya	Bandung	481.20	4.05
Gedebage	Bandung City	355.17	2.99
Cicalengka	Bandung	303.09	2.55
Rancasari	Bandung City	70.10	0.59
Panyileukan	Bandung City	19.17	0.16
Cinambo	Bandung City	14.23	0.12
Cikeruh	Sumedang	5.73	0.05
Dayeuh Kolot	Bandung	3.05	0.03
Cimanggung	Sumedang	1.84	0.02
Buahbatu	Bandung City	1.02	0.01
Total area		**11,886.87**	**100.00**

3.4 Verification

Verification of the results of the analysis was carried out through field surveys. As many as 30 location points, based on image analysis of flood-prone areas, were chosen by purposive sampling. The ground checks were conducted between 6 and 12 August 2018. Figure 3-3 showed the point locations of ground checks. Figure 3-4 showed the examples of the field condition of flood-prone areas in floodplains. We found that 28 locations are Floodplains, 1 location is Ox-Bow Lake, and 1 location is River Course. Based on geomorphological point of view, Floodplain, Ox-Bow Lake and River Course are flood-prone areas.

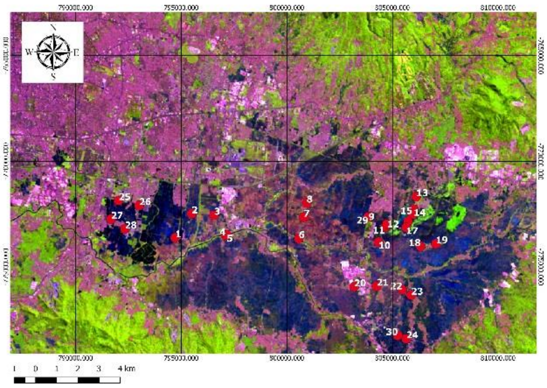


Figure 3-3: The point locations of ground checking (red dots)

Location 17: 06.98489° S / 107.75792° E

Location 19: 06.97846° S / 107.76930° E

Location 22: 06.98629° S / 107.76608° E

Figure 3-4: Examples of the field condition of flood-prone areas in floodplains

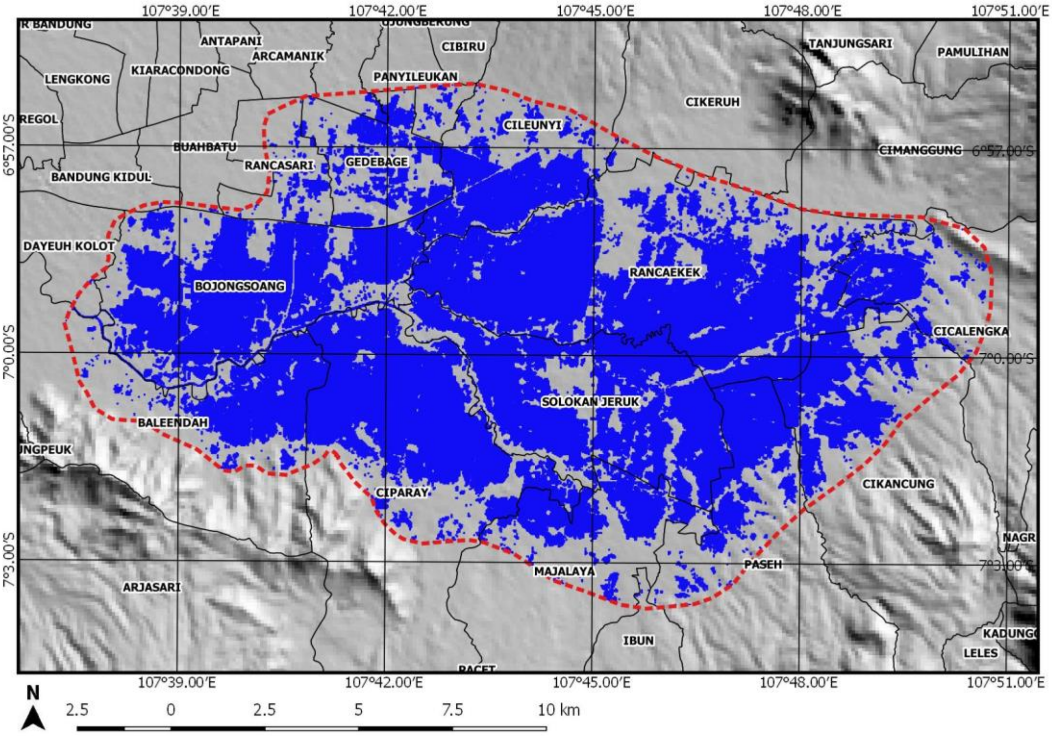


Figure 3-5: Flood-prone area (in blue) in the Bandung basin, compiled above the SRTM30 DEM. The red polyline indicates the outer boundary of the flood-prone area.

We also tried to compare the flood-prone areas with the flood vulnerability map in the Bandung basin resulting from the research of Darwin *et al.* (2018). Darwin *et al.* (2018) tried to compose a flood vulnerability map in the Bandung basin using the Chi-square Automatic Interaction Detection (CHAID) method. The comparison results show that both have a similar pattern, where the flood-prone area produced is included in the high and moderate hazard classes in the flood vulnerability map composed by Darwin *et al.* (2018).

4 CONCLUSION

MNDWI is the appropriate parameter to be used to detect flooded areas in the Bandung basin area that have heterogeneous land-surface conditions. The flood-prone area map can be composed based on flood events, identified as inundated areas in the Landsat-8 images. The estimation of the flood-prone area in the Bandung basin is 11,886.87 ha. Most of the flood-prone areas are in the subdistricts of Rancaekek, Bojongsoang, Solokan Jeruk, Ciparay, Cileunyi, Bale Endah, and Cikancung. The area geographically or naturally is a water habitat area. Therefore, if the area will be used for residential, this will have consequences that flood will always be a threat to the area. Further research is needed to classify flood–prone area by using more image data representing seasonal conditions.

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REFERENCES

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

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

Dam MAC, Suparan P., Nossin JJ, Voskuil, RPGA and GTL Group, (1996), A chronology for geomorphological developments in the greater Bandung area, West-Java, Indonesia. Journal of Southeast Asian Earth Sciences 14 Nos 1/2:101-115.

Darwin, Kombaitan B., Yudoko G., and Purboyo, H., (2018), Application of GIS on determination of flood prone areas and critical arterial road network by using CHAID method in bandung area. MATEC Web of Conferences 147: No. 02007, 11 pages.

Gao BC, (1996), NDWI a normalized difference water index for remote sensing of vegetation liquid water from space. Remote Sensing of Environment 58:257-266.

Harliani, F., (2014), Persepsi Masyarakat Kampung Cieunteung, Kabupaten Bandung tentang Rencana Relokasi Akibat Bencana Banjir. Jurnal Perencanaan Wilayah dan Kota 25(1):37-57.

Irons JR, Dwyer JL, Barsi JA, (2012), The next Landsat satellite: The Landsat Data Continuity Mission. Remote Sensing of Environment 122:11-21.

Ji L., Zhang L., and Wylie, (2009), Analysis of Dynamic Thresholds for the Normalized Difference Water Index. Photogrammetric Engineering & Remote Sensing (75)11:1307–1317.

Kodoatie R., and Sugiyanto, (2002), Banjir: Beberapa Penyebab dan Metoda Pengendaliannya dalam Perspektif Lingkungan. Yogyakarta: Pustaka Belajar.

McFeeters SK, (1996), The use of normalized difference water index (NDWI) in the delineation of open water features. International Journal of Remote Sensing, 17:1425–1432.

Narulita I., Rahmat A., and Maria R., (2008), Aplikasi Sistem Informasi Geografi untuk Menentukan Daerah Prioritas Rehabilitasi di Cekungan Bandung. Jurnal Riset Geologi dan Pertambangan 18(1): 23-35.

Nuraeni R., Sitorus SRP, and Panuju DR, (2017), Analisis Perubahan Penggunaan Lahan dan Arahan Penggunaan Lahan Wilayah di Kabupaten Bandung. Buletin Tanah dan Lahan, 1(1): 79-85

Raharjo PP, (2017), Understanding and Identifying Natural Hazard for Bandung City Preparedness and Mitigation against Natural Disaster. MATEC Web of Conferences 103: No. 07011, 6 pages.

Rogers AS, and Kearney MS, (2004), Reducing signature variability in unmixing coastal marsh Thematic Mapper scenes using spectral indices. International Journal of Remote Sensing, 25(12): 2317–2335.

Wangsaatmaja S., Sabar A., and Prasetiati, MAN, (2006), Permasalahan dan Strategi Pembangunan Lingkungan Berkelanjutan, Studi Kasus: Cekungan Bandung. Jurnal Geologi Indonesia 1(3): 163-171.

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.

Zanter K. (Ed)., (2015), Landsat 8 (L8) Data Users Handbook, Version 1. Sioux Falls, South Dakota: Department of the Interior, U.S. Geological Survey.