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# Monitoring Changes in the Jakarta Flood Disaster with Using Sentinel 2A Imagery

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## ABSTRACT

DKI Jakarta Province is one of the provinces in Indonesia with a relatively high incidence of flooding since its establishment in the Dutch East Indies era because geomorphologically Jakarta is a floodplain area. On the other hand, land pressure by increasing urbanization in the city of Jakarta results in the increasingly limited availability of decent housing land for the community so that lands that should be water catchment areas and riverbanks are transformed into densely populated flying areas which ultimately reduces water absorption capacity in the Jakarta area. To obtain fast data in identifying flood-affected areas, the technique of identifying the potential extent and distribution of flooding by utilizing the remote sensing NDWI (*Normalized Difference Water Index*) method and/or using the *Modified Normalized Difference Water Index* (MNDWI) method from the *free data* Sentinel 2A satellite can be useful to provide data input to relevant parties in DKI Jakarta Province. Opportunities and constraints The application of NDWI and/or MNDWI techniques will greatly assist mapping activities and identification of the distribution of flood areas as an alternative input to policymakers for action and anticipation of areas with high flood potential. This research is one of the first steps and input to the DKI Jakarta Government in making strategies and roadmaps for flood mitigation in DKI Jakarta.

**Keywords:** remote sensing; Sentinel 2A; NDWI (Normalized Difference Water Index); flooding

## INTRODUCTION

The phenomenon of flooding has been a familiar part of Jakarta's life since the city was founded by the Dutch East Indies government. As early as 1619, it was recorded that Simon Stevin at the request of Piterszooncoe designed a city on the Ciliwung River that was often flooded like Amsterdam in the Netherlands. The canal buildings that have been built as well as the Dutch-era floodgates that were built to overcome flooding problems in Jakarta still exist today, including the Kalimalang flood canal, the Matraman floodgate, and the Rubber floodgate. However, the canals that had been built could not prevent flooding in 1932 and 1933 in Batavia (Haryoso, Budi. 2013; Sinukaban, 2007; Sodikin SSRP, et.al, 2017; Yusuf M, 2016).

Another factor that causes flooding in Jakarta apart from the basin area is because geomorphologically Jakarta is a floodplain. Floodplains are generally located around meandering rivers. < 13 rivers flow through the city of Jakarta, where the Ciliwung River is the river that has the largest contribution to flooding in the city of Jakarta. The Ciliwung River has passed through densely populated settlements and slums. Where the Ciliwung River area is 342 $km^2$, with a flow length of 117 km from its upstream in the Pang Rango Mountain area to its downstream in the Pluit area (North Jakarta).

The results of the calculation show that in 20 years, namely between 2007 and 2027, it is predicted that there will be an increase in economic losses by 15 T, from the original loss value of around 21 T to 36 T in 2027 (Yuhanifia N and Andreas H. 2017). The global phenomenon of climate change triggered by an increase in the average temperature of the earth's atmosphere also affects the severity of flooding in Jakarta. Where the earth's surface experienced a temperature increase of $0.85^0$C (0.65

- 1.06$^0$C) during the period 1880-2012. While the temperature increase in the Indonesian region is recorded at around 0.8/100 years (Nugroho, S.P. 2002; Munawi A, et.al, 2023; Aminah S, 2004; Daris F, 2018).

Global temperature changes can have an impact on climate change, including erratic rainfall patterns, and increases and decreases in rainfall in an area that can cause floods and droughts. Many studies on flooding in Jakarta have been conducted, but this research uses sampling points based on calculations of climate change, namely at the time of the highest rainfall and the lowest rainfall. This mapping uses sentinel 2A satellite imagery which has a better resolution than other lansat imagery and has been carried out on the entire DKI Jakarta area in the last ten years and adjusts to the availability of existing data.

## RESEARCH METHODS

### Material

This research design starts by deepening the problem in the form of secondary data obtained as in **Table 1**. Next, the process is carried out in the form of an *overlay*, *cropping*, puddle extraction, and *threshold value*. Furthermore, *ground check* (checking field conditions), accuracy assessment, and *overlay* flood inundation map.

This research was conducted in DKI Jakarta Province, where the study area was carried out in all administrative city areas, consisting of five administrative cities, namely: Central Jakarta with an area of 47.90 km$^2$, North Jakarta with an area of 142.20 km$^2$, West Jakarta with an area of 126.15 km$^2$, South Jakarta with an area of 145.73 km$^2$, East Jakarta with an area of 187.73 km$^2$. The administrative boundaries of DKI Jakarta in the South and East are bordered by Depok City, Bogor Regency, Bekasi City and Bekasi Regency, in the West by Tangerang City and Tangerang Regency, and in the North by the Java Sea (www. Jakarta.go.id).

DKI Jakarta's environmental conditions are generally hot with maximum air temperatures ranging from 32.7°C-34°C during the day, and minimum air temperatures ranging from 23.8°C-25.4°C at night. Average rainfall throughout the year is 237.96 mm, during the period 2002-2006 the lowest rainfall of 122.0 mm occurred in 2002 and the highest of 267.4 mm occurred in 2005, with air humidity levels reaching 73.0-78.0 per cent and average wind speeds reaching 2.2 m/sec-2.5 m/sec.

The data collection period was carried out in the last 10 years (2013 - 2023) according to the highest and lowest rainfall data from the Meteorology and Geophysics Agency each year. Sampling by taking into account seasonal shifts is carried out due to the influence of climate change that occurs. In 2013, it was recorded as a flood disaster that caused the most losses. So the DKI Jakarta government continues to make infrastructure improvements which at this time are starting to be felt to reduce the incidence of flood disasters.

### Data Collection

The data used in this research includes direct survey data in the field, satellite images, as well as *website* or official social media accounts of several related agencies. For the case of this research, DKI Jakarta flood events in 2013-2023, the data is described in **Table 1**.

**Table 1.** Data Collection

| Data Name | Source | Usability |
|---|---|---|
| Inventory of flood events | 1. Field Survey<br>2. BNPB Indonesia (www.gis.bnpb.go.id)<br>3. BPBD DKI Jakarta | For validation and accuracy of research data |
| Sentinel 2A Imagery Data Level 1C | Sentinels Scientific Data Hub (https://scihub.copernicus.eu/) | For flood inundation identification extraction |
| Administrative Boundary Data | Geospatial Information Agency (BIG) Indonesia (https://tanahair.indonesia.go.id) | To determine the scope of the research data |

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| | | |
|---|---|---|
| | (https://geoservices.big.go.id) | |
| *Digital Elevation Model* (DEM) | Geospatial Information Agency (BIG) Indonesia | To create Subwatershed boundaries and river network systems |

**Satellite Imagery Acquisition**

The satellite image used for flood mapping in DKI Jakarta is the Sentinel-2A satellite image level 1C acquisition in the 2019 - 2023 period. This Sentinel-2A satellite image is *free data* which can be obtained by downloading it at the website: https://scihub.copernicus.eu. The Sentinel-2A satellite is a new generation satellite designed by the European Space Agency</a> (ESA) for earth observation whose entire data can be accessed for free with a temporal resolution of 10 days (single satellite) and 5 days (combined constellation), as well as 12-bit radiometric resolution. In addition, the RGB band resolution is relatively good for land cover mapping. The sensor characteristics of the Sentinel-2A satellite are presented in **Table 2**.

**Table 2**. Sentinel-2A image characteristics

| Name band | Wavelength (μm) | Resolution (m) |
|---|---|---|
| Band 1 Coastal Aerosol | 0,443 | 60 |
| Band 2 Blue | 0,443 | 10 |
| Band 3 Green | 0,560 | 10 |
| Band 4 Red | 0,665 | 10 |
| Band 5 Vegetation Red Edge | 0,705 | 20 |
| Band 6 Vegetation Red Edge | 0,740 | 20 |
| Band 7 Vegetation Red Edge | 0,783 | 20 |
| Band 8 NIR | 0,842 | 10 |
| Band 8b Vegetation Red Edge | 0,865 | 20 |
| Band 9 Water Vapour | 0,945 | 60 |
| Band 10 SWIR-Cirrus | 1,380 | 20 |
| Band 11 SWIR | 1,610 | 20 |
| Band 12 SWIR | 2,190 | 20 |

**Flood Inundation Extraction Method**

The extraction method for flood inundation in DKI Jakarta in this study uses the Normalized Difference Water Index (NDWI) method and/or the Modified Normalized Difference Water Index (MNDWI) method. Both methods are expected to provide satisfactory results in rapid mapping for flood/water body inundation identification.

The process of extracting and mapping flood inundation in this study was assisted by QGIS Software and the *SeNtinel Applications Platform* (SNAP) software from ESA.

***Normalized Difference Water Index* (NDWI)**

An analysis of inundation identification with the wetness index method or *Normalized Difference Water Index* (NDWI) using satellite data on two channels, namely *Near Infrared* (NIR) which has a wavelength of 0.86 μm and 1.24 μm. The 1.24 μm channel has never been used before in the formation of the wetness and green index (*green*). Equation (1) is an elaboration of the NDWI formula (McFeeters. 1996).

$$NDWI = \frac{B03(GREEN) - B08(NIR)}{B03(GREEN) + B08(NIR)} \quad .................. 1$$

The NDWI index results can range from -1 to +1 where *Green* is the band that includes reflected green light and NIR represents reflected near-infrared radiation. This wavelength selection is done to:

(1) Maximize the typical reflectance of water features by using green light wavelengths;

(2) Minimize NIR low reflectance by water features and
(3) Take advantage of high NIR reflectance by terrestrial vegetation and ground features

***Modified Normalized Difference Water Index*** **(MNDWI**)

The MNDWI method utilizes the reflected *Middle Infrared* (MIR) radiation which is much larger than *Green*. Therefore, if the MIR channel (*band*) is used instead of the NIR channel (*band*) in NDWI, built-up land should have a negative value. Based on this assumption, the modified MNDWI replaces the NIR band with the MIR band. <The Modified Normalized Difference Water Index *(MNDWI) can be expressed in equation (2).*

$$MNDWI = \frac{B03(GREEN)-B12(MIR)}{B03(GREEN)+B12(MIR)} \quad .................. 2$$

The MNDWI calculation has three results, namely (a) Water has a positive value that is greater than in NDWI because it absorbs more MIR light than NIR; (b) Built-up land has a negative value as mentioned above and (c) Soil and vegetation have a negative value because soil reflects more MIR light than NIR green light (Sathianarayanan, M. 2018).

**Accuracy Assessment**

Accuracy assessment is an important requirement for the main criteria for classification systems from satellite imagery. Thus, the results of flood inundation maps from Sentinel 2 level 1C satellite image processing using NDWI and/or MNDWI methods need to be tested for accuracy using *Overall Accuracy* and KAPPA Index **(**Wahyuni, S. 2015). The flow chart of this research is presented in **Figure 1</a>.**

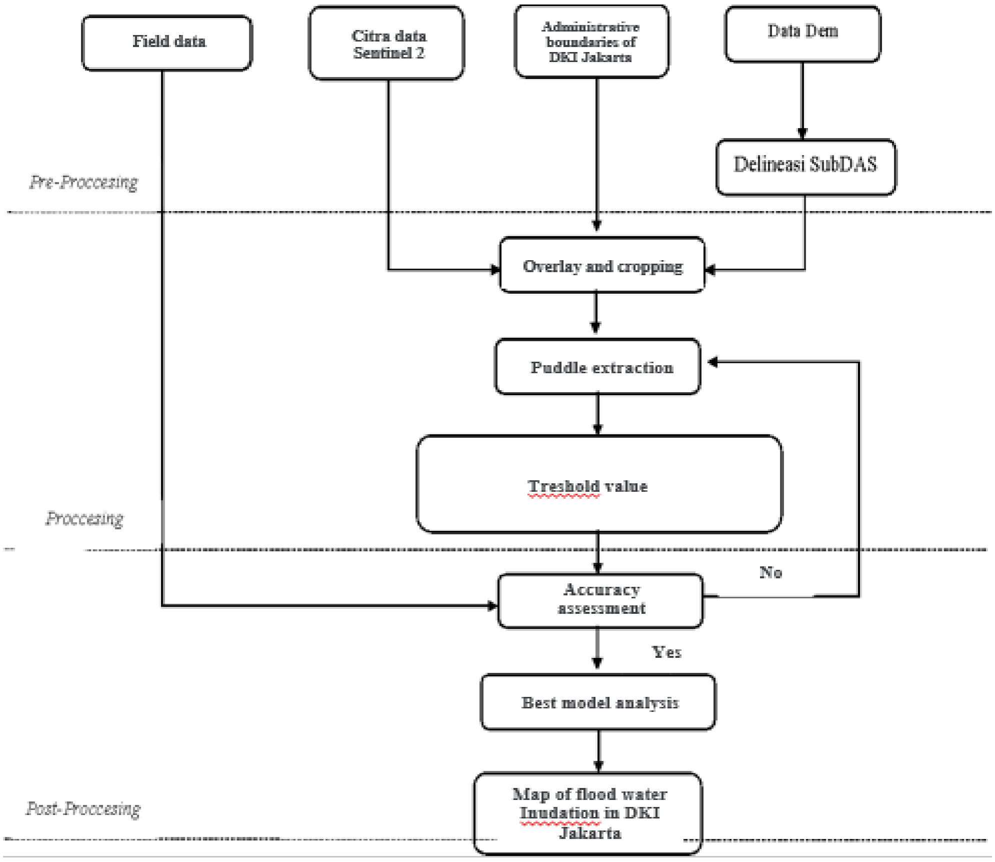


**Figure 1**. Research Flow Chart

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## RESULTS AND DISCUSSION

Based on data from the DKI Jakarta Government and BMKG rainfall data for the period 2014-2020, flooding events in DKI Jakarta fluctuate and almost evenly occur throughout DKI Jakarta. The biggest flood event after 2013 occurred in 2020 where the highest rainfall in DKI Jakarta in January and February amounted to 377 and 277 mm.

**Table 3.** Flood Events in DKI Jakarta for the Period 2014 - 2020

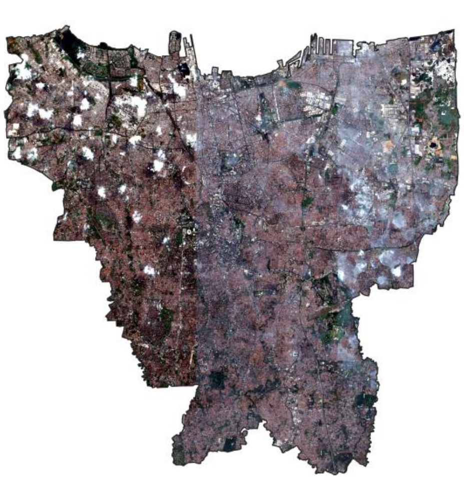
| Year | 2014 | | 2015 | | 2016 | | 2017 | | 2018 | | 2019 | | 2020 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Month | January | February | January | February | March | April | February | March | February | May | March | April | January | February |
| District | 37 | 21 | 15 | 38 | 14 | 18 | 31 | 20 | 24 | 8 | 23 | 17 | 35 | 42 |
| Village | 125 | 45 | 36 | 133 | 32 | 44 | 67 | 40 | 43 | 17 | 43 | 34 | 151 | 167 |
| Rate Rate Water Level (cm) | 10 - 400 | 10 - 300 | 10 - 150 | 10 - 200 | 5-300 | 5-360 | 10-250 | 0-160 | 5-300 | 10-150 | 10-100 | 10-250 | 10 n.d 350 | 5-200 |
| Duration of Inundation (days) | 20 | 20 | 2 | 7 | 2 | 2 | 5 | 3 | 1-6 | 1 | 2 | 1 | 4 | 1 - 2 |
| Affected RW | 634 | 192 | 221 | 615 | 93 | 134 | 216 | 95 | 162 | 47 | 119 | 94 | 390 | 581 |
| Highest Rainfall (mm) | 154,1 | 284 | 134,3 | 277,5 | n.a | 124,5 | 179,7 | n.a | 104,6 | n.a | 130,3 | n.a | 377 | 277 |

Sources: https://pantaubanjir.jakarta.go.id processed

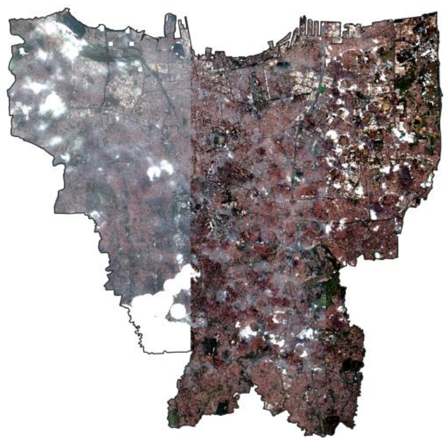
From the data above, it can be seen that the trend of flooding occurs in January - March coincides with the rainy season that occurs in most parts of Indonesia.

Based on the above phenomena and the availability of sentinel 2A data, the analysis of the identification of potential inundation is carried out in the time span of 2019 to 2023 to serve as a starting point in identifying inundation/flooding that occurs in the DKI Jakarta area.

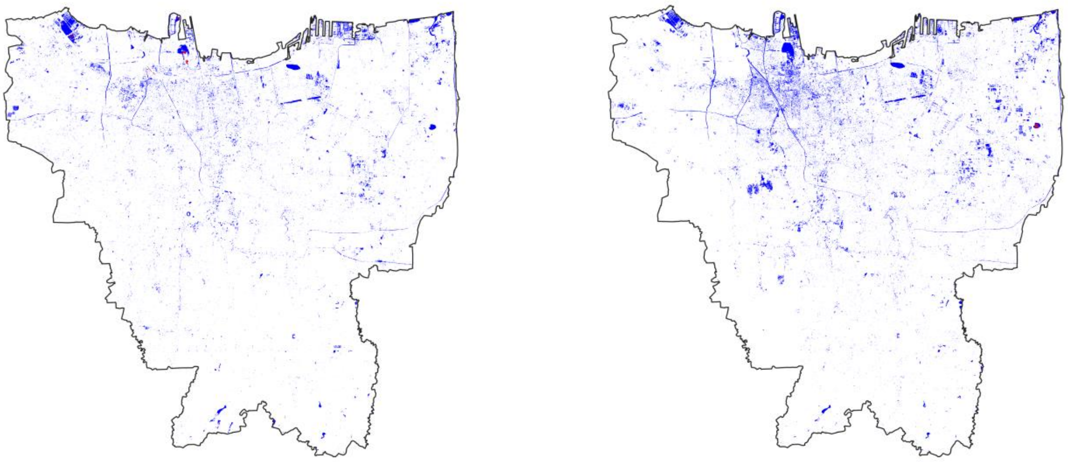
The results of the NDWI and or MNDWI analysis of the DKI Jakarta region for the period 2019 - 2023 are presented in Figure 2.



Sentinel 2A acq 26 March 2019



Sentinel 2A acq 18 January 2020

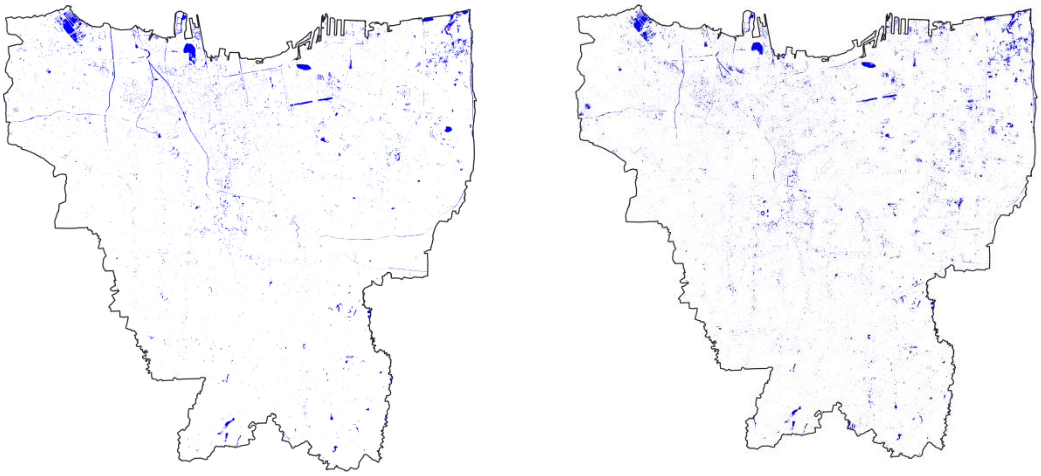


Inundation/flooding on March 26, 2019 based on NDWI method

**Figure 2.** The results of the NDWI and or MNDWI analysis of the DKI Jakarta region for the period 2019 - 2023

This NDWI analysis is in line with flood data sourced from the DKI Jakarta Government in Table 3 where the impact of flooding in 2020 is increasingly widespread as seen from the blue colour on the NDWI analysis map, especially in North Jakarta (Cilincing), East (Pulogadung) and West (Kamal, Cengkareng and Pluit). The heaviest impact occurred in West Jakarta where the area affected by flooding expanded.

Based on the above, NDWI analysis was carried out for other sentinel images in 2021-2023 to identify the area and distribution affected by flooding that occurred in the DKI Jakarta area. The results of the NDWI analysis for the 2021-2023 period are presented in Figure 3.



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Inundation/flooding in the period of February 2, 2021 based on the NDWI method

Inundation/flooding on December 12, 2022 based on NDWI method

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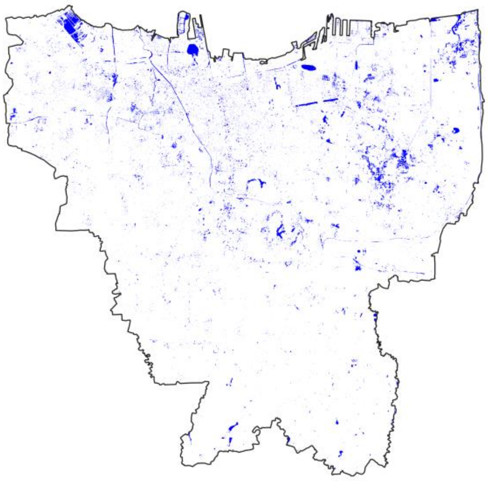

Inundation/flooding in the period of February 27, 2023 based on NDWI method

**Figure 3.** The results of the NDWI analysis for the 2021-2023 period

In this study, NDWI analysis was also carried out on Landsat 8 satellite images as a comparison material in the identification of inundation/flooding that occurred. Tabulation of NDWI analysis comparison using Landsat 8 and Sentinel 2A level 1C data is presented in Table 4.

**Table 4.** Comparison of flood-affected areas based on Landsat 8 and Sentinel 2A satellite imagery data sources

| Value | Year | Date | Size (Ha) |
|---|---|---|---|
| Sentinel 2A | 2013 | n.a | **n.a** |
| Sentinel 2A | 2014 | n.a | **n.a** |
| Sentinel 2A | 2015 | n.a | **n.a** |
| Sentinel 2A | 2016 | n.a | **n.a** |
| Sentinel 2A | 2017 | n.a | **n.a** |
| Sentinel 2A | 2018 | n.a | **n.a** |
| Sentinel 2A | 2019 | 26/March/2019 | 1907.2 |
| Sentinel 2A | 2020 | 18/January/2020 | 2678.15 |
| Sentinel 2A | 2021 | 2/February/2021 | 1413.27 |
| Sentinel 2A | 2022 | 12/December/2022 | 1874.66 |
| Sentinel 2A | 2023 | 27/February/2023 | 2042.34 |
| Landsat 8 | 2013 | 25/August/2013 | 483.3 |
| Landsat 8 | 2014 | 13/Sep/2014 | 442.62 |
| Landsat 8 | 2015 | 14/Jul/2015 | 453.96 |
| Landsat 8 | 2016 | 13/May/2016 | 393.39 |
| Landsat 8 | 2017 | 04/August/2017 | 283.32 |
| Landsat 8 | 2018 | 06/Jul/2018 | 549.9 |
| Landsat 8 | 2019 | 25/Jul/2019 | 479.88 |
| Landsat 8 | 2020 | 25/Jun/2020 | 66.06 |

| | | | |
|---|---|---|---|
| Landsat 8 | 2021 | 11/May/2021 | 552.24 |
| Landsat 8 | 2022 | 01/Jul/2022 | 189.81 |
| Landsat 8 | 2023 | 20/Jul/2023 | 482.94 |

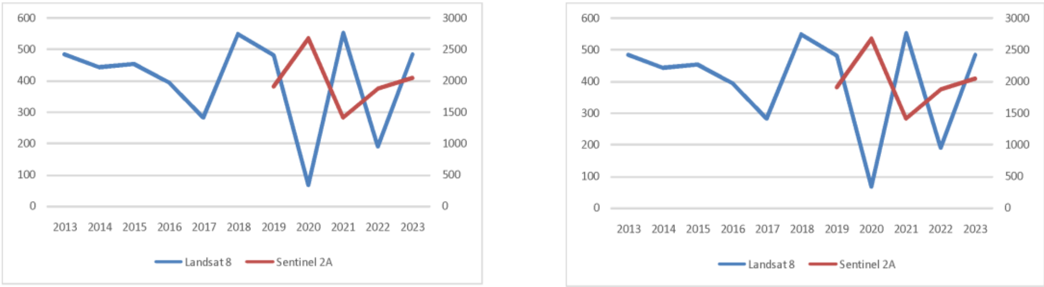


**Figure 4.** Comparison of flood-affected areas based on Landsat 8 and Sentinel 2A satellite imagery data sources

The table and figure above show that the use of sentinel 2A data is relatively more representative to describe the area and distribution affected by flooding compared to NDWI analysis sourced from Landsat 8 satellite image data. This can be seen in the 2020 flood event where data sourced from the DKI Jakarta Government shows the worst event in the last 4 years in 2020 and is in line with NDWI analysis from sentinel 2A imagery.

## CONCLUSIONS

This research is the first step in a series of studies in relation to flood events in DKI Jakarta. The use of free satellite imagery data has the potential to be used as an initial analysis in identifying flood and inundation events that occur in an area.

A decrease in the trend of occurrence and area affected by flooding in DKI Jakarta has occurred in the last 4 years where the largest distribution of affected areas occurred in 2020, amounting to 2,678 Ha, which mostly occurred in North and West Jakarta which are directly adjacent to the Java Sea.

This research is expected to be one of the first steps and input to the DKI Jakarta Government in making strategies and roadmaps for flood mitigation in DKI Jakarta.

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