第 49 卷第 2 期
七月 2024
Diqiu Kexue - Zhongguo Dizhi Daxue Xuebao/Earth Science Journal of China University of Geosciences
https://dqkx-periodicals.com
Vol. 49 No. 2
Oct - Dec 2 0 2 4

DOI: 10.5281/zenodo.14543439

Cloud-Free Mosaic Method for Worldview -3 Images Using Multitemporal Image Analysis and Deep Learning

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Received: 29 October 2024
Accepted: 24 November 2024
Published: 23 December 2024

Abstract: This study presents a novel methodology for generating high-quality mosaics from WorldView-3 satellite imagery, focusing on minimizing cloud cover. The study site, which is located in East Jakarta and its surrounding areas, was chosen due to its diverse land cover types. The proposed methodology involves developing a database to store and manage metadata from multiple WorldView-3 scenes, allowing for an efficient selection of cloud-free image tiles. The algorithm identifies optimal tiles based on cloud cover and acquisition date by dividing the image into several smaller tiles and using a sliding window approach. The selected tiles are then stitched together to create a seamless mosaic. The results demonstrate the effectiveness of the proposed method in generating high-quality mosaics with minimal cloud contamination, providing a valuable resource for applications such as urban planning, environmental monitoring, and disaster management. This study contributes to the advancement of remote sensing image processing techniques, particularly in the context of high-resolution satellite imagery.

Keywords: *Worldview-3, mosaic image, CNN.*

1. Introduction

Monitoring the Earth's surface is greatly enhanced by the availability of satellite imagery, especially across Indonesia's vast regions. Advances in remote sensing satellite technology now offer a wide range of satellite imagery, from low spatial resolutions of over 30 km to very-high spatial resolutions of 30 cm. Additionally, the temporal resolutions of available satellite imagery are varied, providing valuable flexibility. The diversities are highly beneficial for Earth monitoring activities.

High-resolution satellite imagery has a wide range of applications across various fields, utilizing advances in technology and algorithms to improve the quality and usability of images. These images can be applied in various fields, including urban planning, environmental monitoring, disaster management, and military reconnaissance through detailed spatial analysis to assist decision-making (Dorje, Li, Chen, & Poredi, 2024; S. Yang, Pan, & Huang, 2023). With the detailed information provided by very high-resolution (VHR) satellite imagery, VHR imagery has a small size of scenery, so it requires several image scenes to cover an area. In order for earth observation activities to be carried out optimally, mosaic images are needed according to the required observation area coverage. Furthermore, not just any mosaic image is needed, but a mosaic image with minimal cloud cover will be more effective in earth monitoring activities.

Mosaic satellite imagery is essential for remote sensing applications, because it allows for a comprehensive analysis by integrating panchromatic and multispectral images to enhance spatial and spectral information quality (Narasimharao et al., 2023). This type of imagery is crucial in applications such as feature extraction and change detection, as it combines multiple images to create a detailed, cohesive view—especially beneficial for large geographic areas (Abdul-Hammed & Mahdi, 2023). By selecting optimal images with minimal cloud cover, mosaic satellite imagery provides extensive, cloud-free coverage, which is valuable for monitoring natural resources and disaster management (Brahmantara et al., 2022). Additionally, mosaic satellite imagery enables seamless coverage of vast areas that single images cannot capture, allowing for comprehensive urban analysis (Kumar, Kumar, & Gupta, 2022).

Satellite imagery does not consistently provide a clear view. The existence of cloud cover and its shadow significantly disrupts and diminishes information, resulting in inaccuracies in the identification and classification of Earth's surface objects. Consequently, the part of the image with minimal cloud percentage becomes important in composing the mosaic.

The processing of mosaic images in remote sensing imagery is a critical area of research, particularly in light of the expanding visibility and precision of the data. Many algorithms and methodologies have been developed in recent years to improve the efficacy and accuracy of mosaic techniques. To create cloud-free mosaics from satellite imagery, several algorithms and methods are used to overcome the challenge of cloud cover. Multidisciplinary Method, where this method involves enhancing the brightness and chromaticity of the original image, using linear spectral blending to extract cloud regions, and replacing cloud-covered zones with cloud-free zones from other images. A multiscale wavelet-based fusion method is then used to generate the final cloud-free mosaic (Tseng et al., 2008). Iterative Minimization, this method uses cloud-free and cloud-covered images to iteratively minimize the cloud coverage area. This involves generating initial effective mosaic polygons (EMPs) and optimizing them through an iterative quadtree procedure to exclude residual cloud areas, ensuring better radiometric continuity and higher efficiency (Fang et al., 2021). Best Available Pixel (BAP) Composite, this technique creates annual composites by selecting the best available pixels from multiple scenes, eliminating data gaps and radiometric anomalies to create a seamless cloud-free mosaic (Brahmantara et al., 2022; Dimyati & Danoedoro, 2018). Dynamic Variable Patch, this method uses patches as the minimal processing unit, which dynamically adjust their size and position based on cloud coverage and texture consistency. An area-weighted image blending algorithm is used to achieve smooth transitions in the final mosaic (Yu, Pan, Chen, & Wang, 2024). Best Available Pixel (BAP) Composite, this technique creates annual composites by selecting the best available pixels from multiple scenes, eliminating data gaps and radiometric anomalies to create a seamless cloud-free mosaic (Hislop et al., 2018). An approach has been developed to optimize the fusion of aerial remote-sensing imagery by correcting perspective distortion and improving image registration using SIFT. (Scale-Invariant Feature Transform) and wavelet transform, especially for effective disaster response in earthquake scenarios (Bi, Mao, & Gong, 2014; Jia et al., 2015; B. Yang, Li, Yan, & Yu, 2014). . In agricultural areas, the Speed Up Robust Feature (SURF) and SIFT algorithms were compared for high-resolution remote sensing image mosaics. Compared with the SIFT method, the SURF algorithm processed data faster and produced nearly seamless images (Wang & Wang, 2023)

In 2016, the presence of clouds was considered in the development of image mosaics by modifying the Otsu threshold and morphological processing to remove cloudy areas and determine the percentage of cloud cover (Kang et al., 2016). Over time, the number of satellite images created has increased significantly. As a result, the creation of satellite image mosaics, which utilize multitemporal data on multiple images, is driven by the availability of large amounts of satellite imagery. It has been demonstrated by Zheng and colleagues that the proposed technique for image registration, which uses CNN characteristics, significantly improves the effectiveness of the large-scale forestry image mosaic production process (Zeng et al., 2020). A method that utilizes overlapping images is used to generate seamless mosaic images forming 92 military satellite views over Qujing in Yunnan province (Peng et al., 2020). Comprehensive mosaics with minimal cloud interference have been effectively generated through an automated approach that combines an improved cloud detection method with an assessment technique to generate Sentinel-2 image mosaics for the summer of 2015–2019 (Shepherd, Schindler, & Dymond, 2020). The method proposed in this study will generate mosaic images from Worldview 3 satellite images. Unlike other satellite images, Worldview 3 satellite images exhibit different characteristics. Therefore, to obtain Worldview 3 mosaic images, it is necessary to refine the existing methodology. The purpose of this study is to develop a mosaic methodology capable of producing high-quality Worldview 3 satellite image mosaics, especially in overcoming the challenges of dynamic cloud cover. The proposed method will be evaluated and compared with traditional methods using image quality metrics. This study is expected to contribute to the development of high-resolution satellite image processing techniques in Indonesia.

2. Method

2.2. Study area

The East Jakarta area and its surroundings were chosen as the research location in this paper because they have a significant diversity of land cover objects. In addition to residential areas, office, trading center, and green open spaces, this region also includes industrial zones. The diversity of land cover objects produces variations in reflectance values that support the optimal learning process of the software. Based on these considerations, it is expected that the resulting WorldView-3 mosaic image will have minimal cloud cover, allowing it to be further utilized for the extraction of other information. The locations of the study can be seen in Figure 1.

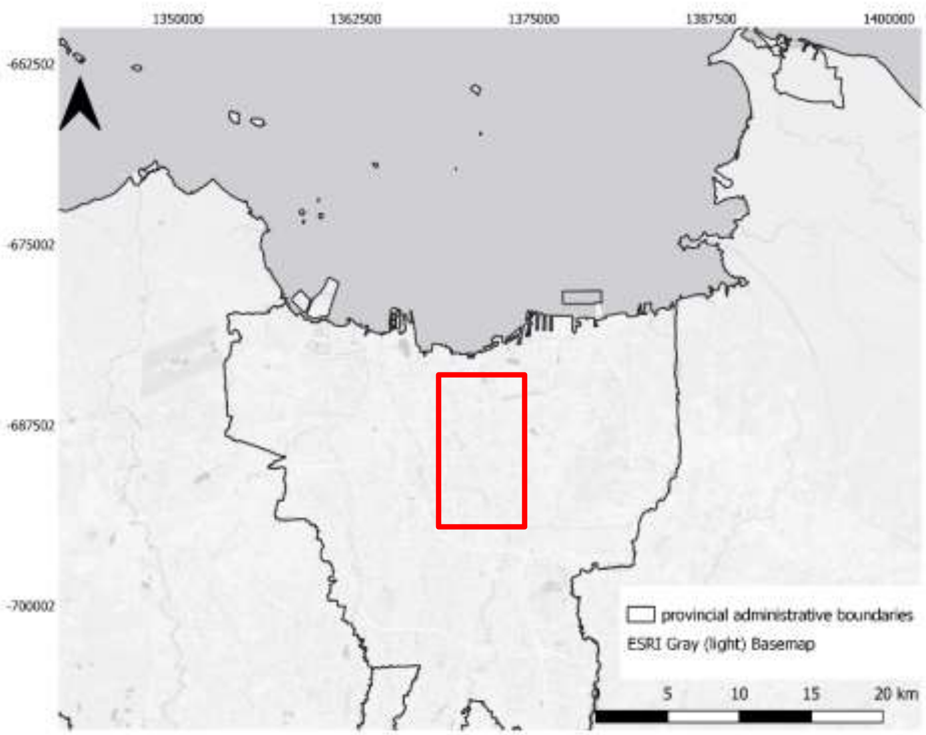

Figure 1. *Study area indicated by the red box*

2.3. Data

The data used in this research is WorldView-3 imagery acquired in 2021. In Indonesia, the authority for ownership of this very high-resolution imagery is managed by the Data and Information Center (Pusdatin) of BRIN. Based on the metadata available from Pusdatin-BRIN, the WorldView-3 imagery used has four spectral channels, namely red, green, blue, and NIR. (Near-Infrared). Throughout the year 2021, there were 12 scenes of WorldView-3 imagery covering the study area location. This information is obtained based on the catalog-inderaja managed by Pusdatin-BRIN. Worldview 3 image scene coverage is shown in Figure 2.

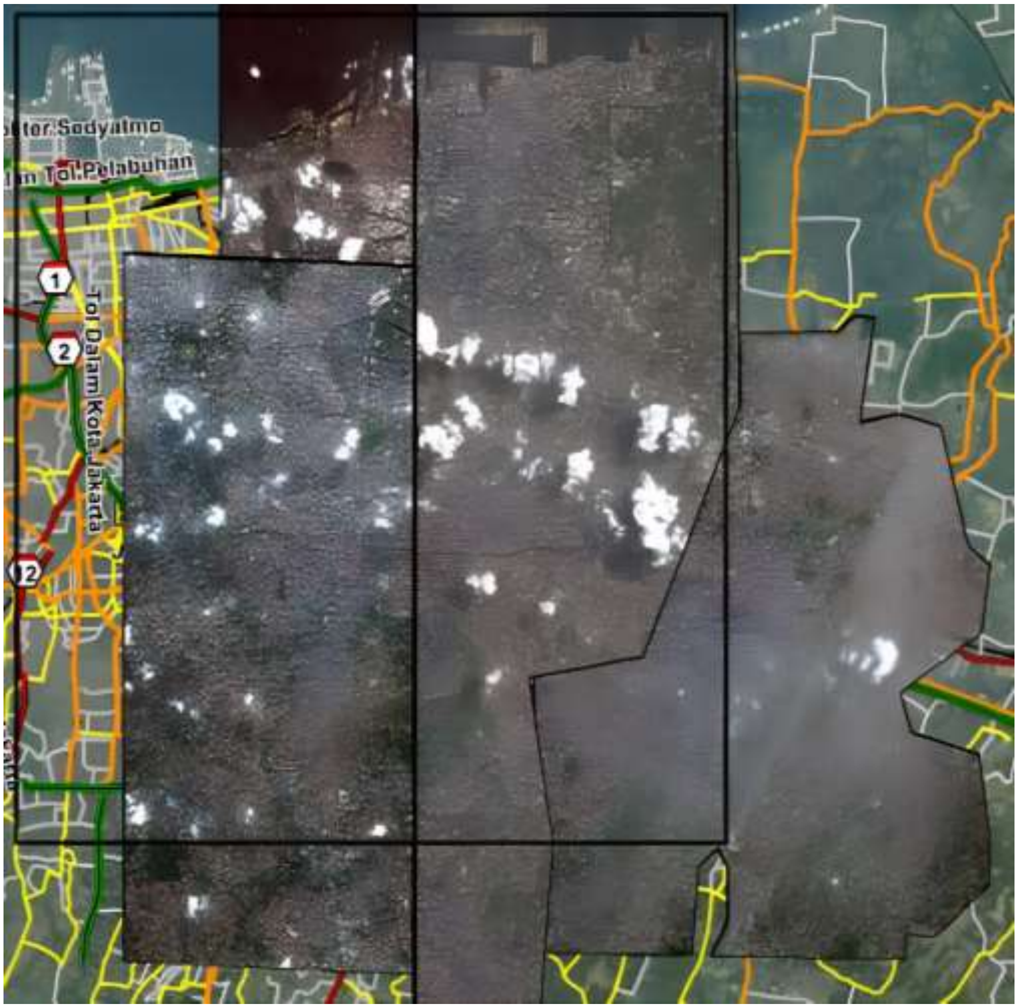

***Figure 2**. The worldview-3 images coverage the study area*

Based on Figure 2, it can be seen that the WorldView-3 image does not have a uniform scene size. Furthermore, despite undergoing cloud masking by the data provider, WorldView-3 images still show the presence of cloud cover in several areas, as shown in Figure 3. Therefore, a method capable of producing WorldView-3 images with minimal cloud cover is highly necessary.

***Figure 3**. WorldView-3 images. The red polygons indicate cloud masking of the source data.*

2.4. Methodology

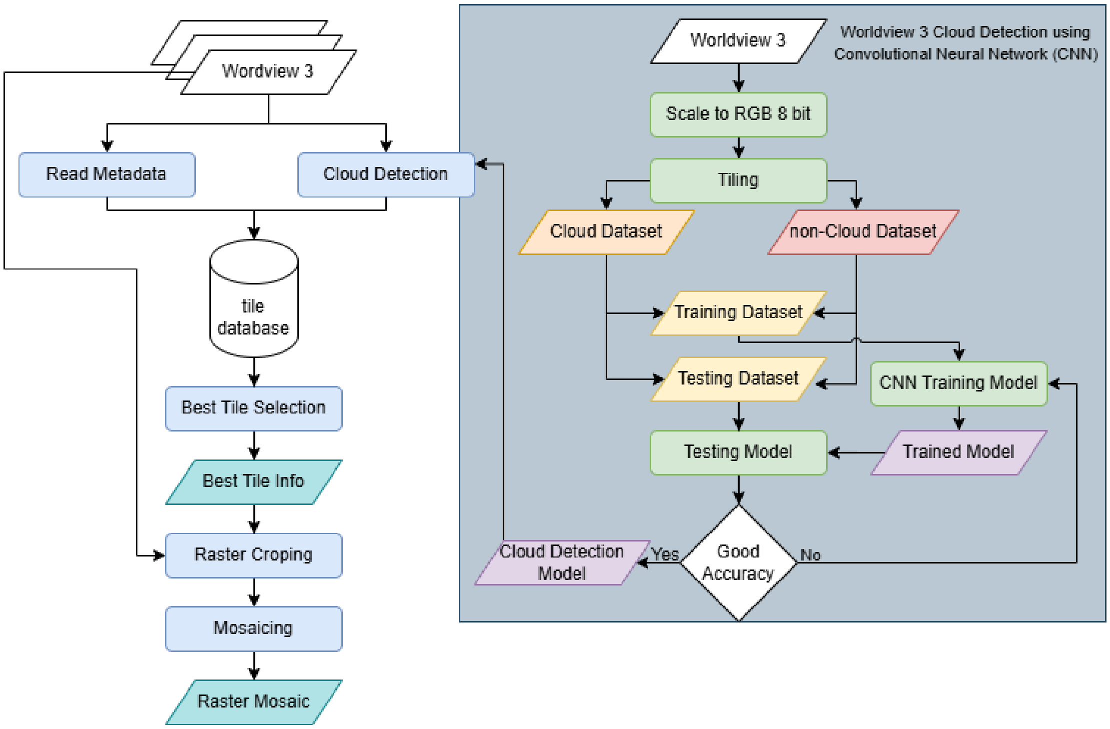

Figure 4. *Flowchart of the proposed method*

The methodology of this study focuses on the development of a high-quality WorldView-3 satellite imagery mosaic technique, especially in overcoming cloud cover constraints. In summary, the research process begins with the collection and formation of a satellite imagery database. Next, the imagery is divided into smaller pieces (tiles) to facilitate analysis. These tiles are then evaluated based on the level of cloud cover and acquisition date to select the best tile. A sliding window technique is used to combine the selected tiles into a complete mosaic. The quality of the resulting mosaic is then evaluated visually and using certain metrics. Thus, this study has succeeded in producing an effective methodology for producing high-quality and consistent satellite imagery mosaics.

The process begins by creating a cloud detection model for WorldView-3 imagery. A single WorldView-3 image is used to build the model. To expedite the process and reduce computational resources, the image is scaled to 8-bit RGB. Subsequently, the image is divided into smaller 250x250 pixel squares, a process known as tiling. These tiles are visually classified as either containing clouds or not to form a dataset. This classification is achieved by creating a label file corresponding to each raster dataset. These labels distinguish between clouds and non-clouds. To enhance model accuracy, contrast stretching is applied to each raster dataset. Contrast stretching rescales the image to encompass all intensities falling within the 2nd and 98th percentiles. Each cloud and non-cloud dataset are divided into training and testing sets in a 70:30 ratio. The model is constructed using a Convolutional Neural Network (CNN). The achieved testing accuracy of 95.74% indicates that the model is sufficiently robust for cloud detection.

The subsequent process involves all WorldView-3 images, reading their metadata to extract information such as order ID, ground sampling distance, root mean square error, UTM zone, off-nadir angle, and date. The WorldView-3 raster is read using a sliding window method to detect clouds and non-clouds. The sliding window is designed consistently, considering UTM coordinates. Consequently, not all parts of the image, especially the edges, might be read to ensure consistency among images with different acquisition dates. The extracted information is stored in a database. Next, the best tiles are selected based on cloud coverage within each sliding window. The database provides information including the coordinates of the sliding window and the identity of the WorldView-3 image. This information is used to crop the image to the size of the tile. The iteration continues until the last sliding window coordinate is reached, resulting in the best tiles that are then mosaicked into a single raster file.

3. Findings

This research database was developed by utilizing Worldview-3 satellite imagery which provides information on the research area during 2021. The aim of this database is to facilitate analysis and data collection by simplifying the process of obtaining certain information from each tile or image obtained from the research carried out. in the research area. The database in question allows the collection and dissemination of information methodically and efficiently, making it easier to carry out further analysis. The data recorded in the database is presented in the table 1.

Table 1. *Characteristics of Information in The Database*

Title	Description	Data type
Order id	scene identity information	Character
Gsd	distance between the centers of two adjacent pixels on the ground in an aerial or satellite image (spatial resolution)	Numeric
Rmse	metric for evaluating the accuracy of predictions (geometric accuracy)	Numeric
Utmzone	a grid-based coordinate system used to provide a high degree of accuracy in mapping the Earth's surface	Character
Eas	easting coordinates of the top left corner of the tile	Numeric
Nor	northing coordinates of the top left corner of the tile	Numeric
Offnadir	image recording angle	numeric
Date	image acquisition date	Date
Cloud	cloud presence, 1 for cloud and 0 for non-cloud	Numeric
Metadata	Directory metadata files are located	character

This database is utilized as a reference in the process of selecting the best tiles to be used in the composition of satellite image mosaics. The database used is PostgreSQL, which is an open-source relational database management system proven to be reliable in handling large-sized data. PostgreSQL was chosen for its reliability in efficiently storing and managing data, especially in activities involving satellite image processing that require the storage of large amounts of raster data.

Additionally, PostgreSQL offers a variety of modules that facilitate their integration with a variety of programming languages, such as Python. PostgreSQL can be connected to Python applications through these modules, facilitating quicker and more convenient access, manipulation, and processing of data. This is crucial in the automation process to ensure the efficient processing of satellite image data.

Reading the metadata file and the raster file from the satellite image is the subsequent phase in this process. The raster file contains the actual image data that will be utilized in the image mosaic creation process, whereas the metadata file contains critical information about the image. Images that are still in the form of scene or vast image segments are cropped to a tile size of 250x250 pixels. The objective of this cropping is to extract small portions of the image that can be individually processed as mosaic tiles. In this manner, each tile can be selected and chosen based on its quality and relevance in the construction of a complete image mosaic.

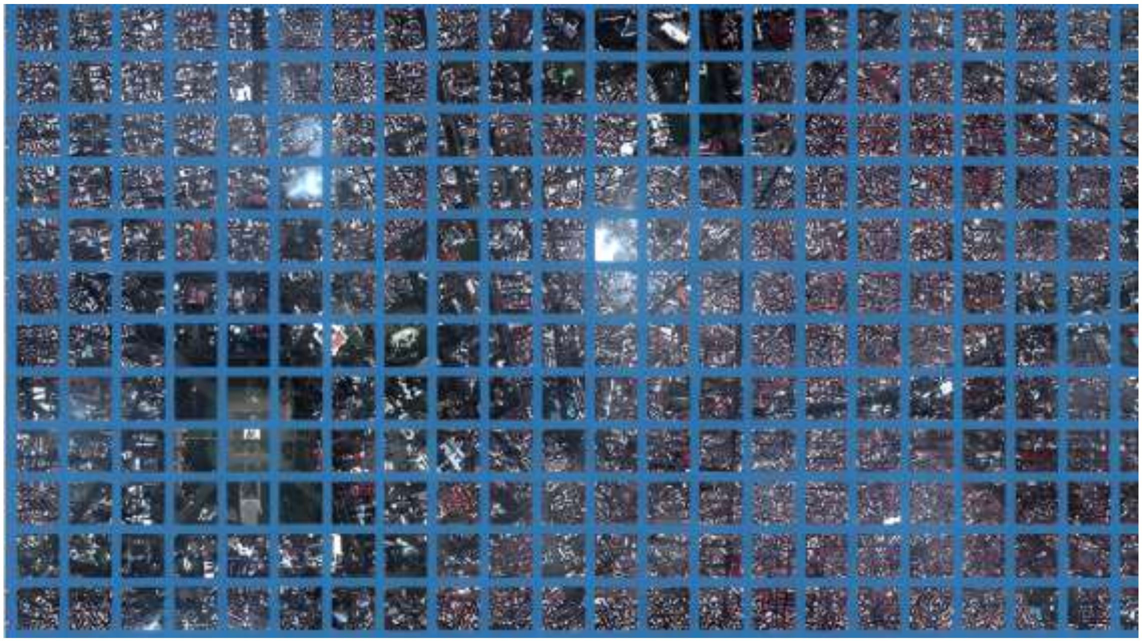

Figure 5. *Tile cutting illustration measuring 250x250 pixels*

The image that has been divided into tiles is the result of high-resolution ortho-pansharp processing, specifically 16-bit RGBN (red, green, blue, and near-infrared) bands with a spatial resolution of 0.3 meters per pixel. The purpose of this process is to enable the analysis or mapping of a large area, and each tile that is generated encompasses a relatively small but detailed area. In a single recording scene, 5,390 tiles were acquired, comprising 4,219 clear tiles and 1,217 cloud-covered tiles. This distinction is significant because clear tiles yield more precise interpretations of observation results than cloud-covered tiles.

If the generated raster file consists of several scenes, then the entire file must be merged into one complete raster file. This raster merging is to ensure uniformity of appearance and minimize the boundaries between scenes that could disrupt the image mosaic result as shown on Figure 6.

Name	Date modified	Type	Size
21JUN02031444-M3DS_R1C1-014231396140_01_P001	8/10/2021 7:05 PM	TIF File	131,074 KB
21JUN02031444-M3DS_R1C2-014231396140_01_P001	8/10/2021 7:06 PM	TIF File	131,074 KB
21JUN02031444-M3DS_R1C3-014231396140_01_P001	8/10/2021 6:59 PM	TIF File	110,222 KB
21JUN02031444-M3DS_R2C1-014231396140_01_P001	8/10/2021 7:00 PM	TIF File	131,074 KB
21JUN02031444-M3DS_R2C2-014231396140_01_P001	8/10/2021 7:04 PM	TIF File	131,074 KB
21JUN02031444-M3DS_R2C3-014231396140_01_P001	8/10/2021 7:02 PM	TIF File	110,447 KB
21JUN02031444-M3DS_R3C1-014231396140_01_P001	8/10/2021 7:04 PM	TIF File	131,074 KB
21JUN02031444-M3DS_R3C2-014231396140_01_P001	8/10/2021 7:04 PM	TIF File	131,074 KB
21JUN02031444-M3DS_R3C3-014231396140_01_P001	8/10/2021 7:05 PM	TIF File	109,924 KB
21JUN02031444-M3DS_R4C1-014231396140_01_P001	8/10/2021 7:02 PM	TIF File	131,074 KB
21JUN02031444-M3DS_R4C2-014231396140_01_P001	8/10/2021 7:07 PM	TIF File	131,074 KB
21JUN02031444-M3DS_R4C3-014231396140_01_P001	8/10/2021 7:01 PM	TIF File	77,598 KB
21JUN02031444-M3DS_R5C1-014231396140_01_P001	8/10/2021 7:01 PM	TIF File	45,058 KB
21JUN02031444-M3DS_R5C2-014231396140_01_P001	8/10/2021 7:00 PM	TIF File	49,154 KB
21JUN02031444-M3DS_R5C3-014231396140_01_P001	8/10/2021 7:02 PM	TIF File	28,642 KB
21JUN02031444-M3DS-014231396140_01_P001.IMD	8/10/2021 7:02 PM	IMD File	5 KB
21JUN02031444-M3DS-014231396140_01_P001.IMD.pox	12/15/2022 5:18 PM	POX File	104 KB
21JUN02031444-M3DS-014231396140_01_P001.TIL	8/10/2021 7:00 PM	TIL File	11 KB
21JUN02031444-M3DS-014231396140_01_P001	8/10/2021 7:06 PM	XML Document	23 KB
21JUN02031444-M3DS-014231396140_01_P001_README	8/10/2021 7:02 PM	Text Document	1 KB
21JUN02031444-M3DS-014231396140_01_P001-BROWSE	8/10/2021 7:06 PM	JPG File	151 KB
INTERNAL	8/10/2021 7:01 PM	Text Document	1 KB

Figure 6. *Example of several raster image scenes that need to be combined into one image*

The next step in the satellite image mosaic process is reading the image raster using the sliding window method, where this window serves as a framework to observe small parts of the image sequentially. The window used comes from tiles cut in the previous stage. When the system scans the image at each stop point, it will record metadata information and identify whether the area in the window contains clouds or not. This information is then recorded in the database for further analysis.

The borders of the image are intended to be disregarded by the system. This is done to prevent the presence of incomplete data segments at the margins, which could potentially impact the analysis results. Furthermore, the system rounds the window positions to ensure that the sliding window process is able to operate consistently across the entire image, even if the data is collected on various acquisition dates. This normalization is crucial to guarantee that each window maintains a consistent size and position, thereby enabling a more homogenous analysis in spite of the variations in the position and conditions of the satellite images captured at different times.

In contrast to the acquisition systems on the Landsat-8 and Sentinel-2 satellites, which consistently record specific areas based on the path-row system, image acquisition on Very High Resolution (VHR) satellites is determined by user requirements or requests for specific areas. This implies that the VHR satellite's capturing mechanism is not consistent. The VHR satellite is also capable of off-nadir capturing, which involves capturing at an angle greater than 20 degrees from the nadir position. This capability enables VHR satellites to decrease the time required for revisiting. Nevertheless, the consistency of the recording results is impacted by this flexibility. The image mosaic results demonstrate the sliding window's inconsistency, as the visual appearance may not be consistent across areas due to variations in recording angles and capture periods. This phenomenon is visible in Figure 7 while the tile base mosaic shapefile's location is illustrated in Figure 8, respectively.

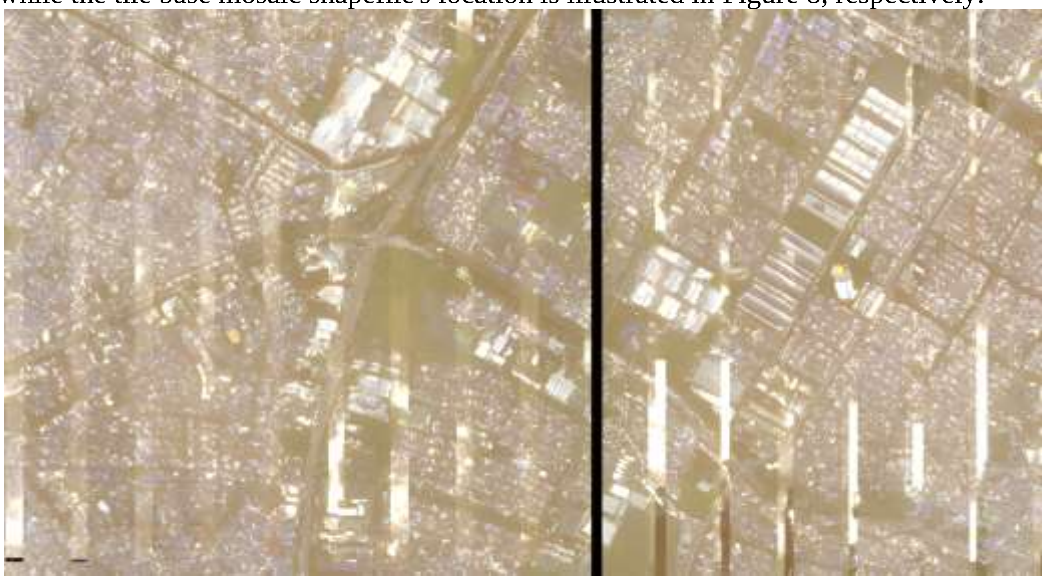

Figure 7. *Mosaic results with sliding windows that are inconsistent between recording dates*

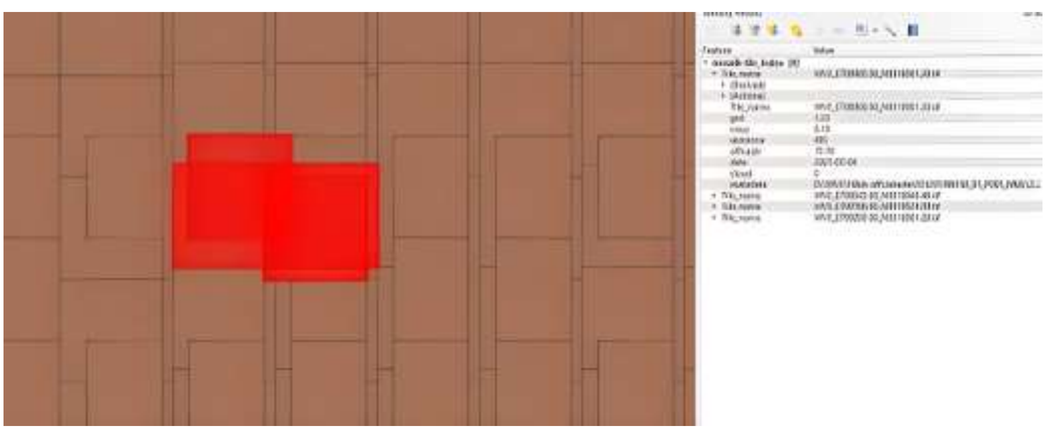

Figure 8. *Tilebase mosaic shapefile*

Based on the previously mentioned, a rounding system was developed to ensure that the sliding window operates consistently on the x-axis and y-axis. This sliding window process is also equipped with stopping locations that are not situated at the border of the image, thereby guaranteeing that each tile is captured within the image area and not snipped at the image boundary. The finest tile from each of the acquisition dates is selected by processing all the Worldview-3 data.

The process of selecting the best tile begins with querying the database to determine the easting and northing coordinates of the locations available in the image. This initial query will generate a list of easting and northing coordinates that have been previously recorded in the database. Based on this list of coordinates, a follow-up query is conducted to select the best tile at each location based on several criteria. The main criteria used are the cloud image clarity level, where the cloud value must be equal to 0, and the most recent acquisition date to ensure optimal visual quality. The shapefiles resulting from this processing serve as mosaic metadata shown in Figure 9.

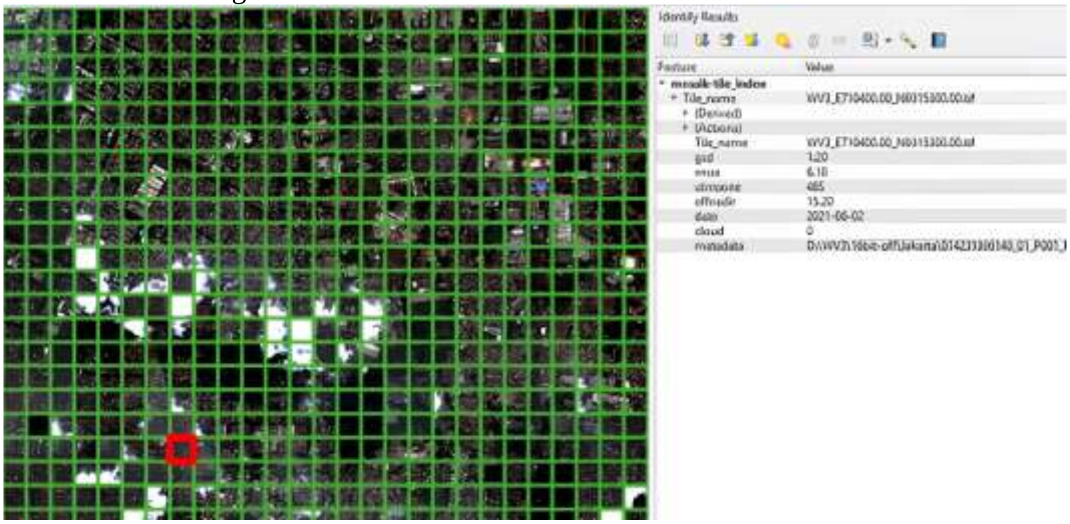

***Figure 9**. Information of the red box shapefile*

After the best tile is determined, the tile is cut from the original image using the query result as a reference. The result of this cutting will contribute to the formation of a mosaic image that combines the best pieces from the entire mapped area. For example, if the query results show that the best tile at the easting x and northing y coordinates is the tile with order ID 014231396140_01_P001, then the system will retrieve raster data from that location with a size of 250 pixels around the specified coordinates. This tile is then used to build the overall mosaic image, resulting in a more complete and integrated view of the area as shown in Figure 10.

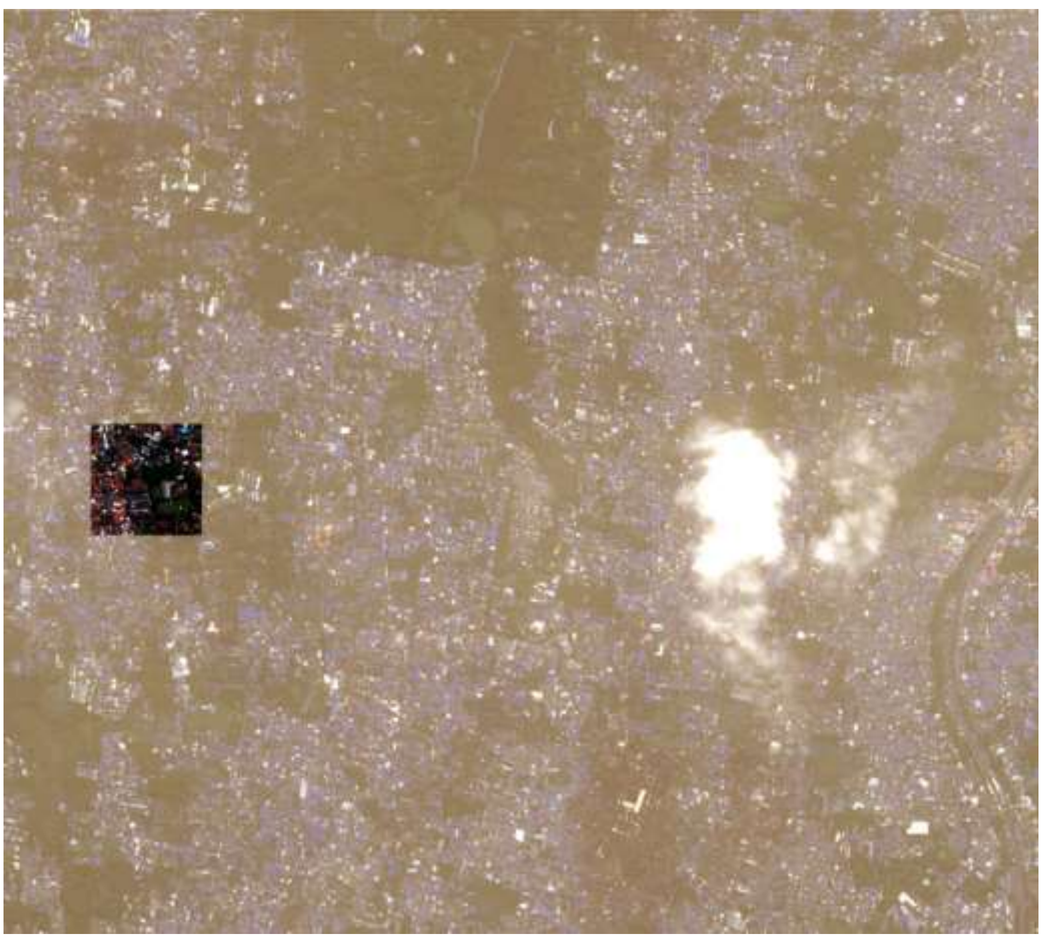

***Figure 10**. Example tile taken from worldview-3 014231396140_01_P001*

To see the overall mosaic result, a mosaic preview needs to be created. In this process, each best tile is combined into a single file with a lower resolution, allowing us to see the overall picture without needing a large file size. Merging or file merge is done through a special command in OSGeo Shell, a command-line interface commonly used for geospatial data processing.

By executing this command, each tile will be processed and merged, resulting in a single low-resolution mosaic preview file. The final result is an overall mosaic view that is easier to access and analyze. This is very helpful in the quality checking, correction, and further data compilation processes. This mosaic preview also provides a complete visual overview, allowing for effective evaluation before further processing of data at full resolution. The image of Worldview-3 mosaic preview can be seen in Figure 11. The zoomed-in pictures show the difference between the image before and after image mosaicking process.

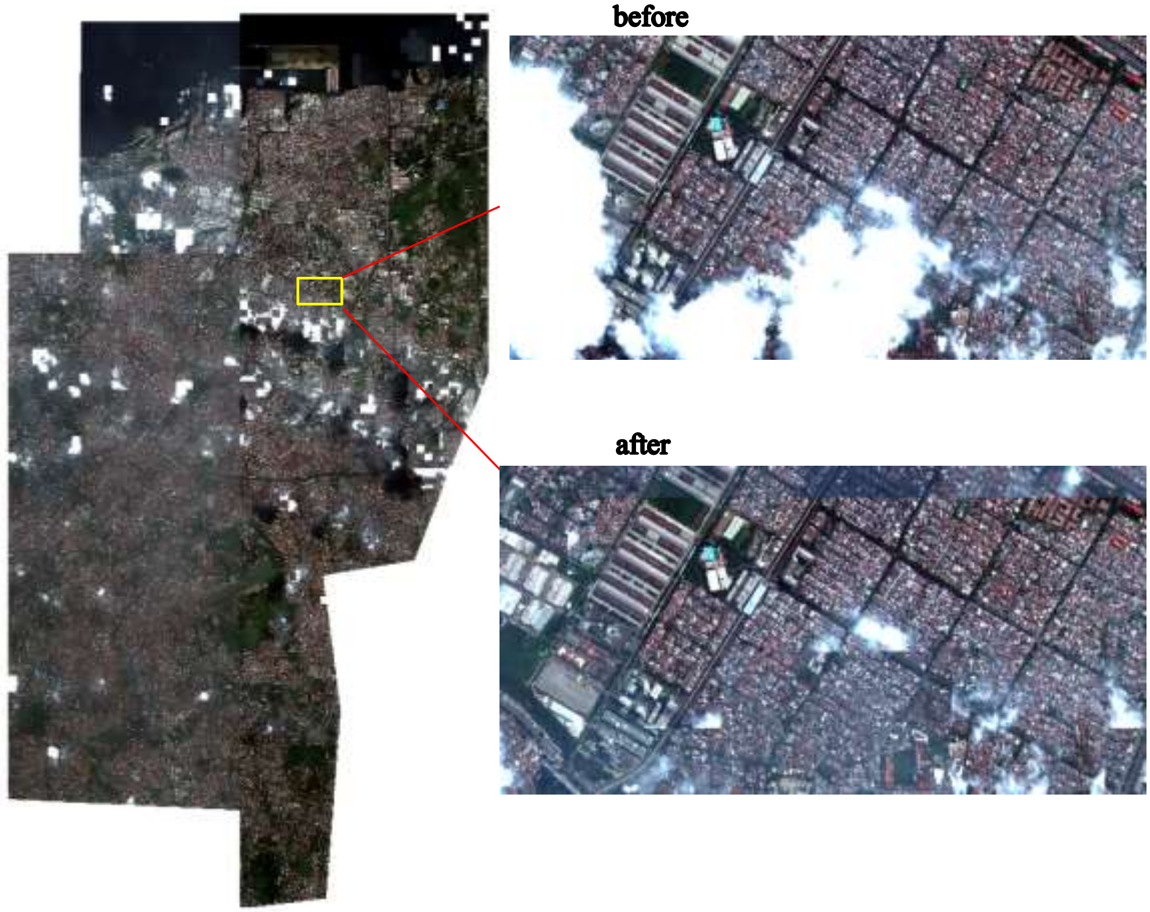

Figure 11. *The result of mosaic image Worldview-3*

4. Conclusion

This research has successfully overcome the challenges in creating high-resolution satellite image mosaics, especially in dealing with cloud cover variations. Through the development of a comprehensive method, this research produces high-quality and consistent WorldView-3 image mosaics. The use of a database to store image metadata and the application of image cropping and optimal tile selection techniques significantly improves the accuracy and efficiency of the mosaic process.

The Cloud-Free Mosaic Method using Multitemporal Image Analysis and Deep Learning can provide several important implications in the provision of geospatial data, urban planning, agriculture, and disaster response which include increasing data coverage and accuracy because this method can produce high-resolution and cloud-free mosaic data with wider and more comprehensive coverage. Automation of cloud removal and mosaic process reduces the time and human operator required for image preprocessing, thereby increasing operational efficiency. The availability of data in a broad mosaic and cloud-free form can facilitate better decision-making in various sectors such as disaster response, environmental monitoring, city planning and others.

Research on the Cloud-Free Mosaic Method opens up opportunities for the development of broader applications, such as monitoring land cover changes, spatial planning, and disaster mitigation. One of the opportunities that can be done is the application of the method to other high-resolution satellite data and integrating it with data from other sensors and in increasing the ability to produce seamless mosaic data on images with varying spatial resolution and spectral resolution. There is also the opportunity to combine it with high-resolution synthetic aperture radar (SAR) or LiDAR data to replace optical sensors and improve the quality of mosaics in certain areas such as urban or forest areas. Further studies can also be carried out in improving deep learning models such as for real-time processing and integration with open-source platforms that can provide convenience and can increase collaboration in remote sensing research.

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