JESE 4 (1) (2024)

Journal of Environmental and Science Education

https://journal.unnes.ac.id/journals/jese

Mapping the Dynamics of Mangrove Density in Alas Purwo National Park using the ARVI Index

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DOI: https://doi.org/10.15294/jese.v4i1.5721

Article Info

Received 3 January 2024
Accepted 15 April 2024
Published 28 April 2024

Keywords:
Remote Sensing, Landsat-8, Mangroves, Radiometric Correction, ARVI

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Abstract

This study aims to compare the sensor/Top-of-Atmospheric (TOA) reflectance correction method and surface reflectance correction in the ARVI (Atmospherically Resistant Vegetation Index) vegetation index transformation application. The resulting comparison of the two has a correlation that is not much different, sensor reflectance correction (R = 0.9723) and surface reflectance correction (R = 0.9781) are both able to represent mangrove forest canopy density well. The model accuracy resulting from the surface reflectance correction RMSE 1.408 and MAPE 0.48%, is higher than that of the sensor correction (TOA) which has an RMSE value of 2.184 and MAPE 1.34%. For advanced remote sensing analysis, it is better to perform radiometric correction of surface reflectance because the reflectance value used for analysis is the true reflectance value. The condition of mangroves in Grajagan Bay in Alas Purwo National Park is very well preserved, this is shown by the mangrove canopy density >50% increased by 49.11 Ha in a period of 7 years from 2016 to 2023.

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p-ISSN 2797-0175
e-ISSN 2775-2518

INTRODUCTION

Indonesia is one of the coastal countries with the longest coastline. This makes it the largest mangrove ecosystem in the world, although mangrove deforestation also often occurs (Fariz et al, 2024; Jabbar et al, 2021; Rahadian et al, 2019). The way to reduce mangrove deforestation is through coastal management policies which are supported by data such as mangrove change maps (Fariz et al, 2020; Irsadi et al, 2019). Remote sensing is the most effective method for mapping mangroves rather than terrestrial methods (Khakhim et al, 2018). According to Kuenzer et al. (2011), the data obtained from applying remote sensing to the identification of forest ecosystems, especially mangrove forests, are useful for creating habitat inventory, monitoring changes, evaluating ecosystem, biomass productivity, mangrove regenerative capacity, and disaster management, planning field survey, assessing water quality, and identifying ecological and biological processes in an ecosystem.

Remote sensing provides forestry data that has many utilizations, including the estimation of forest density using the vegetation transformation index. The vegetation transformation index is a mathematical model that involves several channels at the same time and gives a new and more representative image of vegetation properties (Danoedoro, 2012). This index can be classified into four groups, viz., general vegetation index, vegetation index that emphasizes soil background, vegetation index that stresses atmospheric influence, and vegetation index that utilizes other indices. Each of them can minimize atmospheric scattering noise.

Atmospherically Resistant Vegetation Index (ARVI) is a transformation index that can minimize significant atmospheric influence, namely, noise, on object identification. Atmospheric noise changes the pixel values of the objects. According to Jensen (2005) and Danoedoro (2012), ARVI involves a bad vegetation transformation index because it contains many noises; hence, the results are not in line with the actual condition. However, the blue channel in the formula of ARVI can minimize these atmospheric noises. This makes previous studies show that ARVI is the best index for mapping mangrove canopy density at Grajagan Resort (Khakim et al, 2018; Putra, 2016). However, studies examining canopy density dynamics using ARVI are still rare. Current studies still include mangrove area dynamics and single year density studies (Utomo et al, 2021; Parela & Kamal, 2020). Therefore, this study will map the dynamics of mangrove canopy density at Grajagan Resort and compare it based on sensors with surface reflectance. This study is urgent considering that mangrove density data can be used to map carbon stocks (Rijal et al, 2023). Mapping carbon stocks at Grajagan Resort, Alas Purwo National Park is important because it has a variety of mangrove species with high carbon prices (Rijal et al, 2024).

METHOD

The study area is Grajagan Bay in Alas Purwo National Park, Indonesia which is geographically situated at 114o13’20.203”-114o20’45.979” E and 8o35’52.79”-8o37’28.697” S, as illustrated in the map (see Figure 1). The dominant water movement that takes place in the estuary is seawater, indicating water salinity as the determinant of the zonation. Salinity divides the estuary into two zones, namely, the south and north zones. The field observation in each zone found 15 mangrove species in Grajagan Bay, Alas Purwo National Park. However, according to Rusila Noor et al (1999), 27 species are growing in Alas Purwo National Park and the forest managed by Perum Perhutani (a government-owned company that focuses on forest planning, management, protection, and production).

The data used in the study were the images of Landsat-8 OLI that has two sensors carried by the eighth Landsat generation, namely, OLI and Thermal sensors. However, this study used the OLI sensor. Landsat-8 OLI consists of nine bands whose details are as follows: 1) coastal band (0.43-0.45 µm); 2) blue band (0.450-0.51 µm); 3) green band (0.53-0.59 µm); 4) red band (0.64-0.67 µm); 5) near-infrared band (0.85-0.88 µm); 6) SWIR1 band (1.57-1.65 µm); 7) SWIR2 band (2.11-2.29 µm); 8) panchromatic band (0.50-0.68 µm); and 9) cirrus band (1.36-1.38 µm); all of which have 30-meter resolution for multispectral imaging and 15-meter resolution for panchromatic imaging (Irons, 2015). The Landsat-8 OLI image was used because it had a complete band with a minimum cloud cover above the ground, i.e., 11.6%. When the cloud cover above the ground is >30%, the targeted object is unidentifiable and the imaging result is useless. Landsat 8 images used are January 2016 and October 2023 recordings. Landsat 8, January 2016 recording for field sampling and model correlation tests, while October 2023 recording for mangrove canopy density modeling and density accuracy.

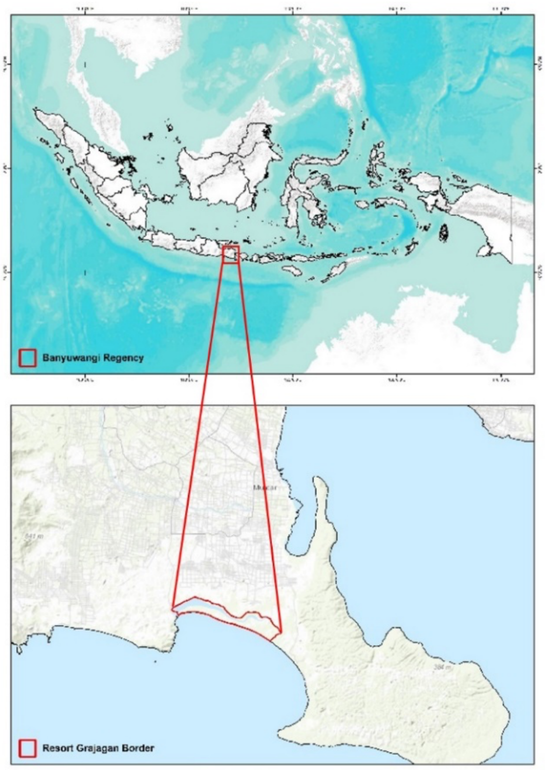


Figure 1. Study Area

Radiometric and atmospheric corrections aimed to obtain biophysical parameters (Jensen, 2005). The atmospheric correction was conducted using histogram adjustment. Histogram adjustment is an easy and simple technique to discard the offset value of the image (Danoedoro, 2012). Before the atmospheric correction, the Landsat-8 OLI images required sensor correction, which used the top-of-atmosphere (ToA) approach. The image was processed using the software ENVI 4.8.

Field measurement was conducted in 2016 at Alas Purwo National Park using a gap fraction method or hemispherical photography method. In this study, the canopy is the measurement object because remote sensing has a higher ability to identify the coverage of vegetation canopy. The canopy density was measured using fisheye portraits. The resulting image was processed using software that produces canopy density in the field.

This method using hemispherical photography is very effective, representative, and efficient in determining vegetation canopy density (Fariz et al, 2023). According to Khakhim et al (2018), the field data collection process needs to consider the average height of the researcher and do it in a squatting position.

This study used the Atmospherically Resistant Vegetation Index (ARVI), particularly its ability to minimize atmospheric influence. The formula used in ARVI is as follows (Somvanshi and Kumari, 2020; Wijaya and Bashit, 2019) :

$$ARVI = \frac{\rho NIR - [\rho Red + \gamma(\rho Blue - \rho Red)]}{\rho NIR + [\rho Red - \gamma(\rho Blue - \rho Red)]}$$

ARVI uses one of the bands or channels that can minimize atmospheric noise, which is the blue channel. According to Danoedoro (2012) and Jensen (2005), the blue channel can minimize atmospheric noise because it scatters in the atmosphere. Thus, ARVI was deemed representative of identifying the density of mangrove forests.

RESULT AND DISCUSSION

According to Nisa'a (2015), Shatila (2013), and Faizal and Amran (2005), the vegetation transformation index applied to the assessment of mangrove forest density results in 80% accuracy. However, the results of ARVI are less appropriate to the actual condition compared to the results of radiometric corrections. Digital image processing requires radiometric correction to provide raw image and spectral reflection, which is not represented by the actual condition. The spectral reflection of an object plays an important role in further analysis. According to Widhaningthas et al (2020), the steps of radiometric correction use the raw image of a Digital Number (DN) that is transformed into ToA (Top of Atmospheric); then, the atmospheric correction is applied using surface reflectance. According to Soenarmo (2009), radiometric correction aims to improve pixel value to fit with the expected value by considering atmospheric noises. According to Chander et al. (2007), this correction is very important to obtain the expected result of image processing.

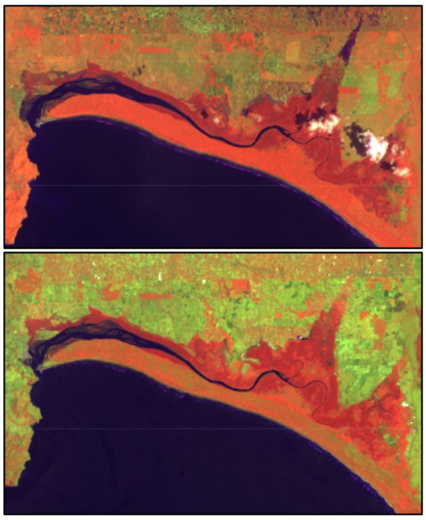


Figure 2. Landsat 8 images with composite (NIR- SWIR- Green) February 2016 (above) and October 2023 (bottom)

Mangrove has a different spectral reflectance value from other vegetation objects. Viewed from the Landsat 8 image composite (NIR-SWIR-Green) mangroves have a different color from other vegetation. Mangroves have a more striking color that has a bright hue compared to other vegetation objects such as non-mangroves can be seen in Figure 2, making this composite easier to classify mangroves and non-mangroves in Grajagan Bay in Alas Purwo National Park. The result of the radiometric correction is the real reflection value of the tested object. In this study, the tested object was the mangrove forest and the real reflection value of the mangrove forest was the canopy. The real reflection of the object is considered as the reference for the formula used in the vegetation transformation index. This study compared the influence of radiometric correction on sensor reflectance and surface reflectance. The sensor reflectance correction was conducted using a top-of-atmosphere (ToA) approach, while the surface reflectance correction was conducted using histogram adjustment. ToA offers sensor correction using zenith and azimuth angles of the sun, while histogram adjustment uses the reflection values of an object.

The comparison of pixel values obtained from raw data (DN), sensor radiance, sensor reflectance correction, and surface reflectance differs, as presented in Table 1, due to the significant difference in measurement references. The measurement reference in sensor correction is the result of adjusting to actual conditions using the recording angle, while the surface correction is based on the actual reflection of the targeted object.

Table 1. The comparison of the pixel value

Methods	Band 2			Band 4			Band 5		
	Min	Max	StDev	Min	Max	StDev	Min	Max	StDev
Digital Number	8201	52772	3341.0	6170	55310	3822.8	5669	59916	6961.5
Sensor Radiance	36.81	733.06	45.44	6.25	624.8	40.47	3.78	382.3	44.69
Sensor Reflectance	0	1	0.008	0	1	0.009	0	1	0.16
Surface Reflectance	-0.1	0.99	0.11	-0.1	1.06	0.009	-0.1	1.16	0.15

Vegetation index transformation processing will be carried out on sensor reflectance and surface reflectance corrected images. the results of the Landsat 8 index transformation processing have a range of pixel values that can be seen in Table 2. The range of values produced between the two is very different. This is influenced by several factors in image radiometric correction and the method used, namely normalized vegetation index transformation. the difference in the resulting range for this mangrove object will later be taken field observations to obtain reference data on the actual canopy percentage. Sampling for field observations was done by purposive sampling, this was chosen so that the distribution of samples represented each class of mangrove canopy density in Grajagan Bay, Alas Purwo National Park. There are two types of samples taken, namely samples for model correlation tests and samples for model accuracy tests.

Table 2. The comparison of ARVI pixel value

Methods	ARVI		
	Min	Max	StDev
Sensor Reflectance	-0.008	0.877	0.131
Surface Reflectance	0.226	1.126	0.112

The sampling process for measuring canopy density in the field uses the hemispherical photography method. The results of the canopy density processing can be done using the can-eye software (Weiss and Baret, 2010). The process is carried out by calculating the average canopy density from the results of hemispherical shooting. because one sample not only takes one photo but five photos are taken according to the Landsat-8 pixel area which is in an area of 90 square meters. An illustration of sampling and photo processing using can-eye software can be seen in Figure 3.

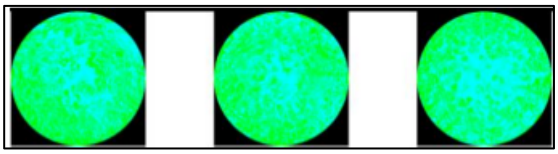
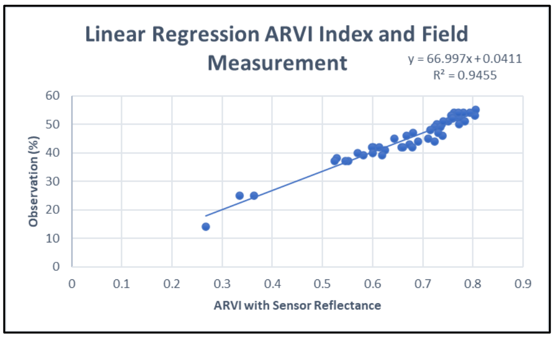


Figure 3. Result of processing hemispherical photography

The range of the reflection values obtained from ARVI was considered as the reference for estimating mangrove density and identifying the correlation between the estimated values from satellite image processing and the results of field measurement. According to Umarhadi and Syarif (2018), modeling mangrove canopy density using regression analysis has conditions that must be met for advanced analysis, namely having a significant correlation.



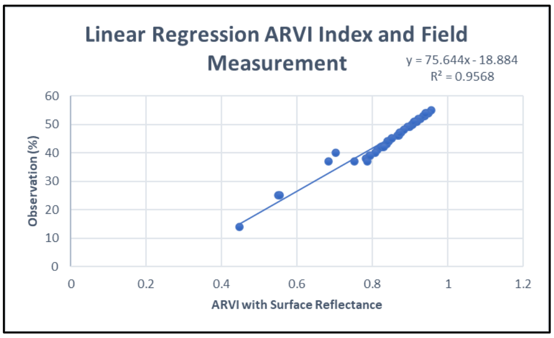


Figure 4. The regression graph between the observation and the surface reflectance ARVI (bottom) and the observation and the sensor reflectance (above)

The graphs of linear regression in Figure 4 show that the actual condition and the ARVI estimated mangrove forest density are similar. The mangrove forest density was estimated using ARVI with sensor reflectance correction. The R2 and correlation (R) between actual mangrove density and estimated mangrove density from ARVI with sensor correction are 0.9455 and 0.9723, respectively. Meanwhile, the R2 and correlation (R) between actual mangrove density and estimated mangrove density from ARVI with surface correction are 0.9568 and 0.9781, respectively.

Table 3. The statistical comparison

Methods	R	R^2	Formula Model
ARVI Sensor Reflectance	0.97	0.94	y = 66.99x + 0.04
ARVI Surface Reflectance	0.97	0.95	y =75.64x - 18.88

According to Hadi (2000), the minimum value of correlation in a statistic is (R) 0.5, this value is a reference in determining the model built means it has represented 50% by the actual conditions. The results of the accuracy test in this study found that the ARVI model for mangrove canopy density detection had almost the same correlation test value between ARVI using sensor correction (97.23%) and ARVI with surface correction (97.81%). The surface correction is slightly superior (0.58%) because the pixel values used are the actual reflected values of the object. Surface correction is more suitable for advanced analysis in remote sensing. If for quick analysis up to sensor correction (TOA), it is accurate enough. The resulting canopy density mapping model needs to be tested for accuracy, the most effective method is using RMSE/ Root Mean Square Error (Kamal et al, 2016; Putra et al, 2023). The level of accuracy using MAPE (Mean Absolute Percentage Error) is the average value of the absolute difference that exists between the value of the prediction and the realized value which is stated as a percentage of the realized value (Nabilla and Ranggadara, 2020). This study uses two accuracy tests, namely RMSE and MAPE.

The best accuracy of the results of the mangrove crown density model in Grajagan Bay Alas Purwo National Park is a surface correction that has an RMSE value of 1.408. If the accuracy is expressed in MAPE mangrove crown density model produced has an average error rate of 0.48% of field observation data. The mangrove canopy density model is very representative according to the actual conditions accurately. The level of mapping accuracy for sensor correction has an RMSE value of 2.184. If the accuracy of using the mangrove canopy density model the resulting MAPE has an average error rate of 1.34% of the field observation data. The resulting mangrove canopy density model can represent the actual conditions very accurately.

Table 4. The comparison of error accuracy

Methods	RMSE	MAPE
ARVI Sensor Reflectance	2.184	1.34%
ARVI Surface Reflectance	1.408	0.48%

Based on the model built using the analysis of Landsat 8 images recorded in January 2016, it will be applied to the mapping of current conditions using Landsat 8 OLI images recorded in October 2023. This will be a comparison of mangrove density conditions in 2016 and 2023 in Grajagan Bay, Alas Purwo National Park. The sustainability of mangrove forests in Grajagan Bay is still well maintained, this is indicated by the level of mangrove canopy density >50% from 2016 to 2023 has an additional area of 49.11 Ha. This shows the seriousness of the government in the forestry sector to preserve mangrove forests. Mangrove canopy density < 20% has also increased over the past 7 years.

Table 5. The comparison density 2016 and 2023

Density	2016 (Ha)	2023 (Ha)
Low (< 20%)	50.86	68.74
Medium (20- 50%)	444.87	376.42
High (>50%)	349.43	398.54

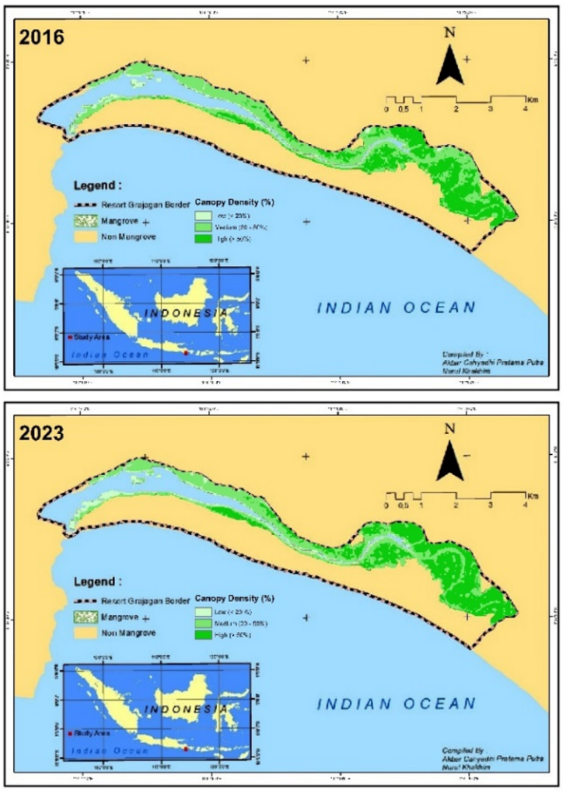


Figure 6. Comparison mangrove canopy density map 2016 (above), 2023 (bottom)

This study still has limitations, such as still using Landsat 8 satellite imagery. For future work, it is necessary to study the dynamics of mangrove canopy density using Sentinel-2 satellite imagery (Binh et al, 2022). Apart from that, future work can also be done using a cloud computing-based platform such as Google Earth Engine which is very helpful for mangrove mapping in Indonesia because it is able to provide free cloud cover and machine learning images (Liu et al, 2021; Amalia et al, 2024; Fariz et. al, 2021; Mahendra et al, 2019). It is hoped that this future work will really help mangrove management at Grajagan Resort, Alas Purwo National Park.

CONCLUSION

The effect of radiometric correction on Landsat 8 images of both sensor reflectance and surface reflectance gives similar results when processing the ARVI vegetation index transformation. The level of correlation between the two is almost the same, namely sensor correction (R = 0.9723), while surface correction (R = 0.9781). The accuracy level produced by both is also very good, the sensor correction has an average error of 1.34%, and the surface correction has an average error of 0.48%. For advanced remote sensing analysis, it is better to make radiometric corrections to surface reflectance because the reflectance value used for analysis is the actual reflectance value. Mangrove conditions in Grajagan Bay in Alas Purwo National Park are very well maintained, this is indicated by mangrove canopy density >50% increased by 49.11 Ha in a period of 7 years from 2016 to 2023.

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