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ANALYSIS OF ABOVE GROUND BIOMASS CARBON MANGROVE DYNAMICS BASED ON REMOTE SENSING TECHNOLOGY IN TIMBULSLOKO AND BEDONO, DEMAK, INDONESIA

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Abstract

Mangrove forests in Timbulsloko and Bedono villages is very dynamic due to land conversion, tidal flooding and land subsidence which are difficult to control. The use of remote sensing technology to monitor mangrove forests has been widely carried out in Indonesia because it can save energy, time and cost. This study aimed to determine the above ground biomass carbon in 2016, 2018, 2020 and 2022 based on remote sensing technology conducted with Sentinel-2 Satellite Imagery processing, and to analyze the dynamic distribution of above ground biomass carbon based on geospatial analysis. The method used in this study can be divided into two categories: satellite image data processing and field survey. The result showed that the area of mangrove forests in Timbulsloko and Bedono from 2016 to 2022 has increased. The mangrove species that have the highest above ground carbon biomass value are *Avicennia marina* followed by *Avicennia alba*, *Rhizophora apiculata*, and *Rhizophora mucronata*. The increase in the area of mangroves in this area is due to natural additions and artificial additions due to mangrove planting conservation carried out by several parties and the awareness of the local residents to protect mangroves.

Keywords: Mangrove, Monitoring, Conservation, Remote Sensing, Blue Carbon.

Introduction

Mangrove ecosystem is a very dynamic ecosystem because it gets direct influence from land and sea. This ecosystem has many benefits, including as a carbon sink or store. Based on research conducted by (Alongi, 2018), mangrove forests can store more carbon compared to other forests. The high ability of mangroves to absorb carbon can increase the contribution of mangroves to reducing the impact of global warming.

Mangrove forests are scattered in several countries in the world with an area of around 19.9 million hectares, one of which is in Indonesia. According to Iksan *et al* (2019), Indonesia is one of the countries that has the largest mangrove forest in the world. One area in Indonesia that has mangrove forests is in Sayung District, Demak Regency. Sayung District consists of several villages, including the Villages of Bedono and Timbulsloko. These two villages have quite extensive mangrove areas when compared to other villages.

The mangrove forests in this area were badly damaged in 1990 because the mangrove forests were turned into ponds and almost became extinct due to coastal erosion due to the construction

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of beaches and ports in Semarang (Damastuti *et al.*, 2018). However, on the one hand, many parties have planted mangroves to restore the function of mangrove forests in coastal areas. Various national and regional mangrove rehabilitation programs have been implemented in these two villages since 1999 by various parties, including the Demak Environment Service, Demak Agriculture Service, Demak Maritime Affairs and Fisheries Service, NGOs, educational institutions, and the private sector (Damastuti *et al.*, 2018).

Deficiencies in area and density will decrease the ability of mangroves to absorb carbon. According to (Windarni & Setiawan, 2018), the ability of mangroves to absorb carbon is influenced by the size of the stem diameter, area and density. The reduction in mangrove area has a major impact on carbon storage and nutrients for ecosystems (Pérez *et al.*, 2018).

The importance of the role of mangrove forests in coastal areas, especially as carbon sinks, makes it necessary to monitor and analyze related to changes in the benefits of mangroves as carbon sinks on a regular basis. Direct measurement in the field will require a lot of time, effort and cost. Therefore, measurements can be carried out using remote sensing technology which will make research more efficient in terms of time, effort and cost. This paper presents the value of above ground biomass carbon mangrove in 2016, 2018, 2020, and 2022 based on remote sensing technology conducted with Sentinel-2 Satellite Imagery processing, and dynamic distribution of above ground biomass carbon mangrove based on geospatial analysis.

Materials and Methods

Time and Location

This study was conducted from October 2022 to May 2023. This study located in Timbulsloko and Bedono Villages, Demak District, Central Java (**Figure 1**).

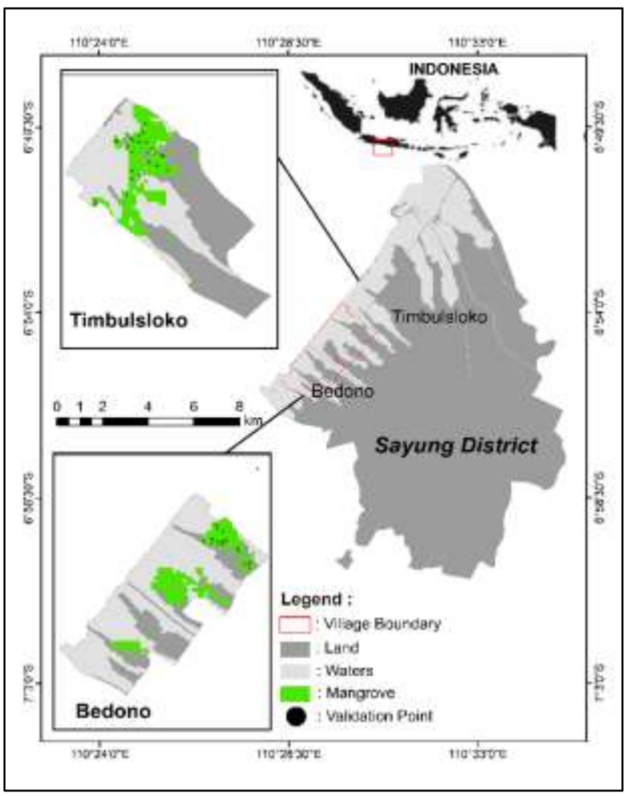

Figure 1. Research Location

Materials

The data used in this study is divided into two, namely primary data and secondary data. The primary data collected by measurement data in the field includes of mangrove diameter data, photos of mangrove canopy, and mangrove species data. The secondary data in this study are Sentinel-2 Satellite Imagery data recorded for 2016, 2018, 2020, and 2022 obtained from the United State Geological Survey (USGS) website. The tools used in this research includes the Global Positioning System (Garmin eTrex 10SEA and Garmin 65s), measuring tape, transect quadratic, mapping software, and camera.

Methods

Pre-Survey Image Processing

Sentinel 2 satellite imagery data was processed to obtain data on the distribution and density of mangroves which will be used to describe the research location and determine sampling points. Mangrove distribution data is obtained by performing radiometric correction, geometric correction, image cropping, masking, digital image classification, and calculation of mangrove density. Radiometric correction aims to restore image pixel values to their original values, carried out using the Dark Object Subtraction (DOS) method. The geometric correction aims to improve the position of the data so that it matches the position on the earth's surface using the linear polynomial rectification method using 3 control points.

Image cropping aims to limit the selected research area so that the image only focuses on the research location. Masking or sea-land separation aims to separate land and water. Classification of digital satellite images is carried out using the supervised classification method to separate mangroves and non-mangroves. The supervised classification method is a method that aims to transform digital satellite image values into certain classes (Khatami *et al.*, 2016). The class division was carried out using the Maximum Likelihood approach which was chosen because it can compare the average value of the diversity between classes whose values are close to the same.

Calculation of mangrove density was conducted using the Normalized Difference Vegetation Index (NDVI), with the following formula:

$$NDVI = (NIR-RED)/(NIR+RED) \qquad 1$$

Where:
NIR : near infrared band (band 8 in Sentinel 2)
Red : red band (band 4 in Sentinel 2)

Field Survey Data Collection

Data collection in the field was conducted based on the results of data processing on mangrove area and density using digital sentinel satellite imagery data which was processed using the Normalized Difference Vegetation Index (NDVI) algorithm. The results of the image processing were used to determine the distribution and density of mangroves which were used to determine sampling points for data collection in the field. The data taken in the field were data on the diameter of mangrove at breast height, mangrove canopy density, and data on mangrove species. The technique used during the field survey was stratified random sampling.

Data on diameter of mangrove at breast height was collected using a tape meter (Wicaksono *et al.*, 2018), and only performed on mangrove that had a diameter of ≥ 5 cm. Mangrove canopy density data was taken using the Hemispherical Photography Method, which is a method of calculating the density of canopy area using a camera that has a fisheye or wide-angel lens from under the tree canopy. This method was chosen because it can easily, quickly, and non-destructively measure forest canopy structural parameters, such as gap fraction (GF), clumping index, and leaf area index (LAI) (Li *et al.*, 2018). Photos were taken 4 to 9 times in one plot this depends on the level of canopy density in one plot. In plots with dense canopies, 4 photos were taken, in plots with medium density canopy, 5 photos were taken, and in plots with sparse canopies, 9 photos were taken.

Calculation of Above Ground Biomass Carbon Mangrove

Calculation of above ground biomass carbon mangroves was conducted by analyzing the spatial characteristics of digital satellite images and by building a carbon biomass model that correlated remote sensing parameter values with carbon biomass values (Wicaksono *et al.*, 2018). Calculation of above ground biomass carbon mangrove includes several stages namely, calculation of mangrove canopy density percentage value, calculation of above biomass value, and calculation of above ground biomass carbon mangrove.

Calculation of the percentage value of mangrove canopy density was calculated using field measurements and satellite imagery from Sentinel 2. Field calculations were conducted by analyzing hemisphere photos obtained by a simple hemispherical photography method in the field. The percentage of mangrove canopy density calculated using digital satellite imagery was calculated by building a model between the NDVI value and the percentage obtained in the field using regression equation.

Above biomass value in the field was calculated with allometric equations. The allometric equations for several mangrove species are presented in Table 1. While the calculation of above biomass value using digital satellite imagery was calculated by modeling a formula constructed from the equation between the canopy density values obtained from Sentinel – 2A imagery and the biomass values obtained in the field using regression equation.

Calculation of the above ground biomass carbon mangrove can be seen from the tree biomass. According to (Hairiah *et al.*, 2020), 46% of the biomass is carbon. Above ground biomass carbon mangrove can be calculated by the formula:

$$C = W \times 0{,}46 \qquad (2)$$

Where:
C = Carbon biomass (tonnes/ha)
W = Biomass per species (tonnes/ha)

Table 1. Allometric Formula for Estimating Mangrove Biomass.

No	Mangrove Species	DBH (cm)	Allometric Equations	Source
1.	*R. mucronata*	5.0 – 48.9	$W = 0.251 \times 0.701\ (DBH^{2.46})$	Temilola *et al.*, (2007)
2.	*A. alba*	5.0-16.0	$W = 0.2901 \times DBH^{2.2605}$	Siregar dan Dharmawan (2009)
3.	*A. marina*	5.0 – 35	$W = 0.308 \times (DBH)^{2.11}$	Comley *et al.*, (2005)

4.	*R. apiculata*	5.0 – 28	$W = 0.235 \times (DBH)^{2.42}$	Ong *et al.*, (2004)

Analysis of Above Ground Biomass Carbon Mangrove Dynamics

Analysis of above ground biomass carbon mangrove dynamics was conducted using a geospatial approach using the overlapping or overlay method. The above ground biomass carbon mangrove data from 2016, 2018, 2020, and 2022 were overlaid using ArcMap to examine the dynamic results of above ground biomass carbon mangrove over the four years.

Results and discussion

The field data collection produced 44 data points, 31 of which were used to build the model and 13 for accuracy testing. An accuracy test aimed to determine the accuracy between the Sentinel 2 satellite imagery values and the measurement values in the field.

Mangrove Species and Density

There are four types of mangroves at the research site: *Avicennia*, *Avicennia alba*, *Rhizophora apiculata*, and *Rhizophora mucronata*. Calculation of mangrove density values using Sentinel 2 satellite imagery using NDVI produces density values between -0.25 to 0.47. The NDVI vegetation index has an R^2 value of 0.80 and an r-value of 0.89 which means that the NDVI vegetation index has a good ability to calculate mangrove density values. The use of NDVI to calculate mangrove density values has been widely used and tends to have high accuracy. Muhsoni *et al.,* (2018) conducted a study using NDVI with Sentinel 2 imagery in Majungan Village, Pademawu District, Pamekasan Regency with an R^2 value of 0.85, Wachid *et al.,* (2018) obtained an r-value of 0.77 in Jor Bay, Aulia *et al.,* (2022) obtained an accuracy of 86.92% with an r-value of 0.85 in Segara Anakan Cilacap.

The calculation of the percentage value of the mangrove canopy density or Leaf Area Index (LAI) in the field was carried out using the hemispherical photography method. While the LAI value based on image data was done by modeling between the field LAI value and the NDVI value with an r-value of 0.92, so it can be concluded that NDVI has a very strong relationship with the percentage value of mangrove canopy density or LAI. Several studies have also proven that there is a strong relationship between LAI and NDVI values. According to Prananda *et al.,* (2020), NDVI has a high relationship value with LAI, with an R^2 value of 0.83.

Mangrove Biomass Value

Calculation of the value of mangrove biomass was carried out in two ways, namely through measurements in the field and processing of Sentinel 2 Satellite Imagery. Calculation of the value of biomass using satellite imagery was conducted by modeling the percentage value of mangrove canopy density or LAI based on image data and field biomass values. The field data used for modeling was 31 data, while 13 field data were used to test the accuracy of mangrove biomass values based on field data and mangrove biomass values based on Sentinel 2 Satellite Imagery data. The relationship between the percentage value of mangrove canopy density or LAI is based on image data and biomass values based on field data have an r value of 0.87 which means that LAI has a very strong relationship with biomass values based on field data with the equation $y = 42.983x - 1372.7$.

Calculation of mangrove biomass values based on field data was carried out using allometric equations for each species. Each species has a different allometric equation. In this study, the results showed that the value of biomass on each transect ranged from 0.5 tons to 2.5 tons. The difference in the value of this biomass is due to the difference in the diameter of the tree trunk at breast height and the number of mangrove tree stands. According to (Windarni & Setiawan, 2018), the larger the tree diameter, the greater the tree biomass. The amount of forest biomass is also determined by diameter, height, wood density, density, and soil fertility Bismark *et al.*, (2018).

Calculation of mangrove biomass using satellite imagery ranged from 0.69 tons to 2.21 tons for each pixel. The accuracy of mangrove biomass value based on field data and image data was evaluated by calculating Root Mean Square Error (RMSE) value and the r value. The data used for the accuracy test were 13 data. The results of the accuracy test showed that the RMSE value was 0.23 and the r value was 0.80 which means that there is a strong relationship. Calculation of mangrove biomass based on data collection in the field and based on satellite imagery results in a high accuracy value so that it can be concluded that the allometric method can be used to calculate surface mangrove biomass properly.

Above Ground Biomass Carbon Mangrove

Calculation of the above ground biomass carbon mangrove value was carried out by multiplying the surface mangrove biomass value by 0.46 which was carried out for each dominant species. Calculations for each species because each species has different allometric equations. The results showed that the highest surface mangrove carbon biomass value was in the species *Avicennia marina*, followed by *Avicennia alba*, *Rhizophora apiculata*, and *Rhizophora mucronate* (Table 2).

Table 2. Above Ground Biomass Carbon Mangrove in Each Dominant Mangrove Species in the Mangrove Ecosystem of Timbulsloko and Bedono Villages.

Year	**Species**				**Total (ton)**
	A. alba	*A. marina*	*R. mucronata*	*R. apiculata*	
2016	33.61	81.81	22.52	40.43	178.37
2018	50.85	113.73	18.32	34.66	217.56
2020	65.49	147.33	24.84	45.01	282.67
2022	67.20	149.43	28.22	72.60	317.45

The value of the above ground biomass carbon mangrove in each species is directly proportional to the area and stem diameter values of each species. This is because the calculation of the value of above ground biomass carbon mangrove in this study was carried out using allometric equations. The allometric equation is constructed from the diameter of a tree trunk at breast height and is directly influenced by the number of mangrove stands in an area.

The high value of above ground biomass carbon mangrove in each species is influenced by the area of mangroves in each species. The *Avicennia marina* species which has the widest area also has the highest above ground biomass carbon mangrove value among the other three species. *Avicennia marina* and *Avicennia alba* have increased in area and value of above ground carbon mangroves every year. However, the species *Rhizophora mucronata* and *Rhizophora apiculata* 2018 experienced a decrease in the value of above ground biomass carbon mangrove. However, the species *Rhizophora mucronata* and *Rhizophora apiculata* in 2018 experienced a decrease in the value of above ground biomass carbon mangrove. This is probably due to degradation of mangrove species that have large tree trunk diameters, but on the other hand there has been new mangrove planting of *Rhizophora* species which has resulted in an increassing in area value and decressing the value of above ground biomass carbon mangrove because the diameter of the stem is still small.

Conclusions

The results of a study on the above ground biomass carbon dynamics based on geospatial analysis indicate that the above ground biomass carbon mangrove for each species in this region has increased from 2016, 2018, 2020, and 2022. However, in 2018 the species *Rhizophora mucronata* and *Rhizophora apiculata* experienced a decrease in the value of surface mangrove carbon biomass. This can happen because of the degradation of mangroves in these two species, but on the one hand there is planting of mangroves in these species which causes an increase in the area of mangroves with a stem diameter that is still below 5 cm.

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References

Alongi, D. M. *Impact of global change on nutrient dynamics in Mangrove Forests*. In Forests, 9, 2018, pp. 1-13.

Aulia, Z. S., R.R. Hidayat and Amron. Carbon Sink Estimation of Mangrove Vegetation Using Remote Sensing in Segara Anakan, Cilacap. *Jurnal Ilmiah Perikanan dan Kelautan*, 14, 2022, pp. 130–141.

Bismark, M., Subiandono, E., dan Heriyanto, N.M. 2008. Keragaman dan Potensi Jenis serta Kandungan Karbon Hutan Mangrove di Sungai Subelen Siberut, Sumatera Barat. Jurnal Penelitian Hutan dan Konservasi, 5, 2008, pp. 297-306.

Damastuti, E., R.D. Groot. Participatory Ecosystem Service Mapping to Enhance Community-Based Mangrove Rehabilitation and Management in Demak, Indonesia. *Regional Environmental Change*, 19, 2018, pp. 65–78.

Hairiah, K dan S. Rahayu. Pengukuran "Karbon Tersimpan" di Berbagai Macam Penggunaan Lahan. Bogor. World Agroforestry Centre – ICRAF, SEA Regional Office, University of Brawijaya, Indonesia, 2020, p. 21. ISBN:979-3198-35-4.

Iksan, M., L. Aba, F.I. Taharu, A. Alfian, D.P.I. Ardyati, Jumiati, W.O.D. Alzarliani, Hardin, and S.H. Larekeng. The diversity of mangrove forests in Kumbewaha, Buton Island, Indonesia. *IOP Conference Series: Earth and Environmental Science*, 343, 2019, pp. 1-6.

Khatami R, G., Mountrakis S.V., Stehman. A meta-analysis of remote sensing research on supervised pixel-based land-cover image classification processes: general guidelines for practitioners and future research. *Remote Sensing of Environment*, 177, 2016 pp. 89–100.

Li, K., X. Huang, J. Zhang, Z. Sun, J. Huang, J. Sun, Q. Xie and W. Song. A New Method for Forest Canopy Hemispherical Photography Segmentation Based on Deep Learning. *Forests*, 11, 2020, pp. 2-16.

Muhsoni, F. F., Sambah, A. B., Mahmudi, M., & Wiadnya, D. G. R. Comparison different vegetation indices for assessing mangrove density using sentinel-2 imagery. International *Journal of GEOMATE*, 14, 2018, p. 42–51.

Pérez, A., W. Machado, D. Gutiérrez, A.C. Borges, S.R. Patchineelam and Sanders, C.J. Carbon accumulation and storage capacity in mangrove sediments three decades after deforestation within a eutrophic bay. *Marine Pollution Bulletin*, 126, 2018, pp. 275–280.

Prananda, A. R. A., Kamal, M., & Wijaya Kusuma, D. The effect of using different vegetation indices for mangrove leaf area index modelling. IOP Conference Series: Earth and Environmental Science, 500, 2020.

Wachid, M. N., Hapsara, R. P., Cahyo, R. D., Wahyu, G. N., Syarif, A. M., Umarhadi, D.A., Fitriani, A. N., Ramadhanningrum, D. P., & Widyatmanti, W. Mangrove canopy density analysis using Sentinel-2A imagery satellite data. *IOP Conference Series: Earth and Environmental Science*, 70, 2017, pp. 1-8.

Windarni, C dan A. Setiawan. 2018. Estimasi Karbon Tersimpan pada Hutan Mangrove di Desa Margasari Kecamatan Labuhan Maringgai Kabupaten Lampung Timur. *Jurnal Sylva Lestari*, 6, 2018, pp. 66 – 74.

Wicaksono, P., Danoedoro, P., Hartono, Nehren, U. Mangrove biomass Carbon Stock Mapping of the Karimunjawa Islands using Multispectral Remote Sensing. *International Journal of Remote Sensing*, 37, 2015, pp. 26-52.