Estimation of Biomass and Carbon Stock Using NDVI from Multispectral Camera in the Revegetation Area of PT Berau Coal

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Abstract*— PT Berau Coal is a company that has held the Coal Mining Work Agreement (PKP2B) since 1983, with an area of approximately 243,146.60 hectares located in Berau Regency, East Kalimantan Province. As a mining industry, the company must play a role in maintaining hydro-orological functions and protecting flora and fauna. The restoration of forest functions is crucial for providing environmental services, including efforts to act as a carbon (C) producing area and absorbing carbon dioxide (CO2). PT Berau Coal has carried out reclamation and revegetation in its post-mining areas, but until now, no research has been conducted in the revegetation areas of PT Berau Coal. Therefore, this study aims to determine the distribution of biomass and carbon stock in the revegetation areas and planting years at the Binungan site of PT Berau Coal from 2015 to 2022. The method used to calculate carbon stock and biomass involves field sampling and remote sensing using MicaSense multispectral aerial photos. Biomass and carbon stock estimation with aerial photos is conducted by calculating the plant greenness index using NDVI, followed by regression with field biomass. The regression model used includes four types: linear, quadratic, cubic, and exponential. These models are evaluated to find the best fit model with accuracy tests using Root Mean Square Error (RMSe), Mean Absolute Error (MAE), and Mean Absolute Percentage Error (MAPE) to determine the modeling accuracy. The results show that the best model for estimating biomass and carbon stock is the exponential regression model with a correlation value of 0.84. This correlation value falls into the category of a fairly high correlation. The RMSe produced in the accuracy test is 15.65, with an accuracy rate of 73%. The estimated carbon stock value for each planting year is 70,817,156.852 Kg/Ha (2015), 79,837,036.531 Kg/Ha (2016), 49,654,443.503 Kg/Ha (2017), 47,047,989.557 Kg/Ha (2018), 35,219,578.867 Kg/Ha (2019), 19,693,198.417 Kg/Ha (2020), 31,335,533.541 Kg/Ha (2021), and 31,335,533.541 Kg/Ha (2022). The modeling results indicate that the older the plants, the higher their NDVI, resulting in greater biomass and carbon stock in the area.

Keywords— Carbon Stock, Biomass, NDVI, Revegetation, Multispectral Aerial Photos.

I. Introduction

Global Warming is one of the most important environmental issues currently drawing attention from various parties around the world. It refers to the increase in the Earth's average temperature due to the accumulation of gases in the lower atmosphere, which trap reflected sunlight from the Earth. According to the IPCC 1995 (as cited in Siregar 2007), ongoing forest degradation can increase carbon dioxide (CO2) emissions in the atmosphere, thereby triggering global warming and climate change. The rise in carbon dioxide emissions is driven by fuel use, deforestation, and land-use changes. According to the East Kalimantan government (Bappeda Kaltim 2018), deforestation and forest and land degradation in East Kalimantan are caused by four sectors: forestry, plantations, agriculture, and mining, as well as others (infrastructure, land encroachment, etc.).

PT Berau Coal Site Binungan is a coal mining company established on April 5, 1983, located in Berau Regency, East Kalimantan Province, with a total concession area of 118,400 hectares. The Binungan site operates using an open-cut mining system with a backfilling method adapted to the coal reserve conditions, quality, and existing geological structure. Deforestation and land-use changes have led to increased carbon dioxide (CO2) emissions. Therefore, efforts are needed to prevent further land degradation, such as revegetation activities, which are a form of land rehabilitation technology caused by human activities (Singh et al., 2002).
One of the government's efforts to address emerging issues is to mandate coal mining companies to conduct reclamation and revegetation. Revegetation involves replanting former mining areas to function as carbon storage areas because the plant ecosystem within them can absorb carbon. An interesting example of reclamation has been carried out by PT Berau Coal at the Binungan site, transforming former mining land into a golf course. Additionally, PT Berau Coal at the Binungan site has been conducting reclamation and revegetation activities from 2005 to the present. However, until now, there has been no measurement of the carbon absorption potential by the revegetation plants. This carbon absorption potential data is also useful as a benchmark for the Indonesian government's commitment to reducing emissions to the international community.

Previous studies on carbon and biomass calculation have been conducted by Rusdiana and Fahmi (2020), who calculated carbon storage in the field on revegetation stands in the post-mining land of PT Holcim Indonesia Tbk. Their study showed that the biomass and carbon

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storage values for the 2005 pine stands were 75.31 tons/ha and 35.39 tons/ha, respectively. In 2012, the biomass and carbon storage values decreased to 12.72 tons/ha and 5.98 tons/ha. Using the same method, Syamsudin Noor, Hafizianoor, and Suyanto (2020) conducted a study to calculate carbon storage in plants on former coal mining land at PT Borneo Indobara. The study showed that carbon storage per hectare in the reclamation area in 2013 was 71.84 tons, with a total of 2,155.24 tons for an area of 30 hectares. In 2015, carbon storage per hectare in the reclamation area was 70.20 tons, with a total of 1,544.45 tons for an area of 22 hectares.

Recent research has utilized higher-resolution imagery using multispectral cameras. de Queiroz et al. (2023) estimated the aboveground biomass (AGB) content in the Cerrado grassland, Central Brazil, using aerial photos from metric photogrammetry. They found an estimated AGB of 18.3 (±13.3) Mg ha^{-1} in three different regions. This result showed a strong correlation (93%) with an RMSE (root mean square error) of 0.16, indicating that this method can be used to estimate AGB in the Cerrado with high accuracy.

Previous studies have mainly focused on carbon stock calculation using visual/digital remote sensing image interpretation or field sampling methods. Therefore, this study focuses on calculating biomass and carbon stock in the revegetation area of PT Berau Coal, Binungan Mine Operation from 2015 to 2022 using tree circumference measurements as primary data and NDVI values from multispectral aerial photos as secondary data to calculate the amount of biomass and carbon stock stored in the revegetation area of post-mining land from 2015 to 2022 at PT Berau Coal, Binungan Mine Operation.

II. METHOD

A. Location

Sampling for this research was conducted in the revegetation area of the Binungan site at PT Berau Coal. The data used for sampling included planting data in both the IPD and OPD revegetation areas from 2015 to 2022, as shown in Figure 1(a), acquired in 2023. The field data acquired consisted of tree circumference data (estimated tree diameter) and aerial photo data using a MicaSense multispectral camera. The aerial photo acquisition was conducted in the same year, 2023. Both data sets will be used to estimate biomass and carbon stock values.

Figure 1(a) shows the distribution of 120 tree sampling points evenly spread across the study area. Data cleaning will be performed to remove outliers, with 70% of the data used for training and the remaining 30% for testing.

B. Normalized Difference Vegetation Index

The Normalized Difference Vegetation Index (NDVI) is an indicator of vegetation density, greenness, and condition in a given area. This indicator is influenced by vegetation cover, density, and greenness levels. It reflects the photosynthetic capacity of vegetation covering the ground surface. The vegetation index is a mathematical combination of the red band and the NIR (Near-Infrared Radiation) band, which has long been used as an indicator of the presence and condition of vegetation. The NDVI value (Equation 1) is calculated using the reflectance of Near Infrared and Red light from plants (Hatulesila, Mardiatmoko, and Irwanto 2019).

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

where:
NDVI = Normalized Difference Vegetation Index
NIR = Spectral reflectance value in the Near-Infra Red band
Red = Spectral reflectance value in the Red band

This index value ranges from -1 to 1, where a value of 1 indicates areas rich in vegetation, a value of 0 indicates very little vegetation, and -1 indicates non-vegetated areas. The typical range for green vegetation is 0.2 to 0.8.

C. Biomass

Biomass plays a role in the carbon cycle, where the amount of biomass in vegetation can be calculated to estimate the carbon stock of the vegetation. To estimate the carbon stock and biomass values of vegetation, the formula established in SNI 7724:11 regarding Measurement and Calculation of Carbon Stock is used. The formula is an allometric equation that can estimate biomass from the trunk, branches, and leaves of vegetation, as shown in Equation (2).

$$B = 0.0912 \times (D)^{2.2} \qquad (2)$$

where:
B = biomass (Ca/ha)
D = Diameter of vegetation (cm)

After calculating the biomass, the estimation of carbon stock is carried out based on SNI 7724:11, which states that 47% of the biomass content is carbon. Therefore, to obtain the carbon estimate, the biomass is multiplied by 47% of the biomass assumed to be carbon, as shown in Equation (3).

$$\text{Carbon Stock} = 0,47 \times B \qquad (3)$$

The calculated carbon stock will be valued at Ca per hectare. The higher the biomass stored in the vegetation, the greater the carbon storage held by the vegetation.

D. Regression

After obtaining the estimated carbon values in vegetation, the next step is to develop a linear regression equation to create a carbon stock estimation model using biomass data that has been calculated with vegetation density information from NDVI multispectral aerial image. Several regression models are used, including linear (4), quadratic (5), cubic (6), and exponential (7).

$$Y = aX \pm b \qquad (4)$$
$$Y = aX^2 \pm bX \pm c \qquad (5)$$

$$Y= aX^3 \pm bX^2 \pm cX \pm d \quad (6)$$
$$Y= e^{aX \pm b} \quad (7)$$

where Y represents the dependent variable (vegetation biomass value), X represents the independent variable (vegetation density/NDVI value), and a, b, c, d are regression coefficients. The accuracy of each of these four regression models will be evaluated based on accuracy, Mean Absolute Error, and Mean Absolute Percentage Error.

E. Accuration Test

The accuracy test is conducted on the image processing previously performed under field conditions. Accuracy testing is calculated based on the Root Mean Square Error (RMSE) using Equation (8):

$$RMSe = \sqrt{(y - y')^2/n} \quad (8)$$

where:
RMSe = nilai Root Mean Square error
y = measured value
yi' = estimated value
n = number of samples

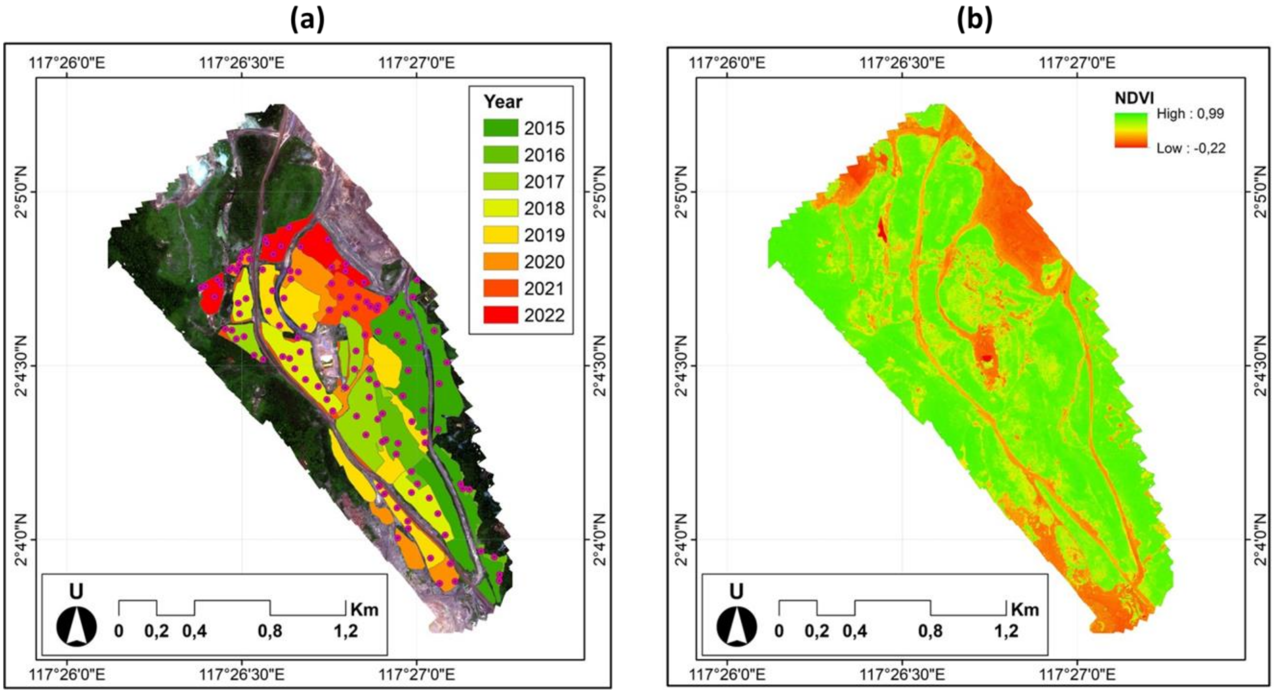


Figure 1. (a) The location and distribution of research sample points at PT Berau Coal Site Binungan, East Kalimantan. (b) Distribution of NDVI (Normalized Difference Vegetation Index) from Multispectral Aerial Camera Photos. All data were acquired in 2023.

III. Results and Discussion

A. Multispectral Aerial Photo Processing

This research utilized a MicaSense multispectral camera with high-resolution vertical aerial photos at 5 × 5 cm. The aerial photos obtained were free from clouds, and the weather conditions during image recording were favorable, with no atmospheric haze. Clouds are considered disruptive as they can obscure parts of satellite images, thus hindering the interpretation process. With such image acquisition conditions, high-quality images were obtained. Transformation of the NDVI vegetation index was conducted to represent the vegetation density levels at the revegetation locations, with NDVI values ranging from -0.22 to 0.99 (as shown in Figure 1(b)).

A total of 120 sample points were scattered across the entire area, then cleaned from outliers, resulting in 72 clean sample points. Out of these points, 70% (59 points) were used for training, and 30% (13 samples) were used for testing. The NDVI results were overlaid with the field sample collection points to obtain NDVI values at the same locations using the "extract by value" method.

B. Revegetation Plant Composition

The field sample collection resulted in a total of 120 plants, consisting of Sengon and Johar plant species. The sampling included 7 Johar plants and 8 Sengon plants per sample, as shown in Figure 2.

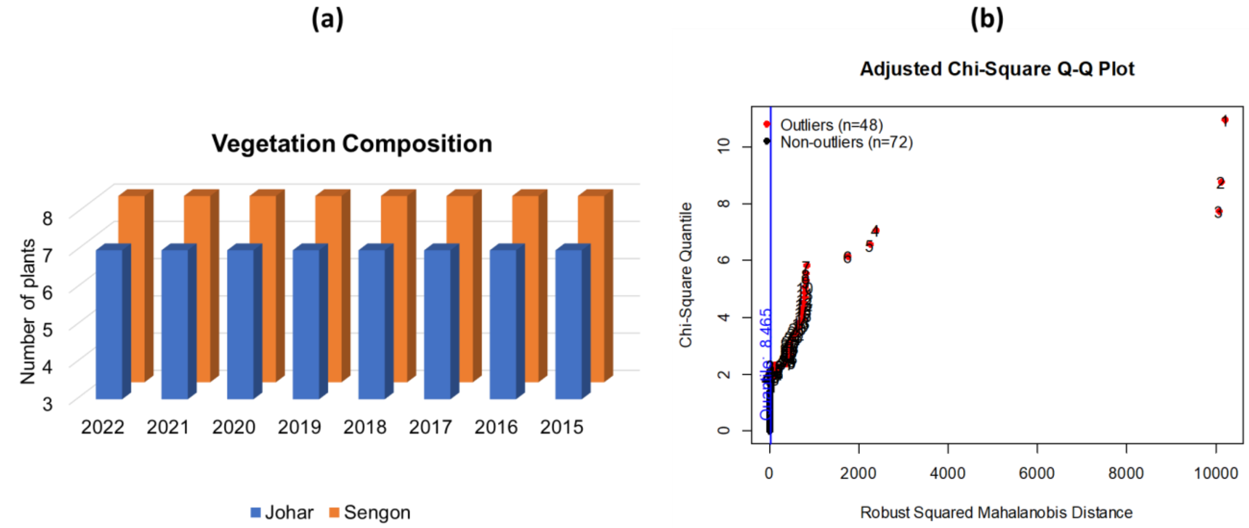


Figure 2. (a) Composition of Plant Species for Each Planting Year. (b) Outlier Detection with Chi Square.

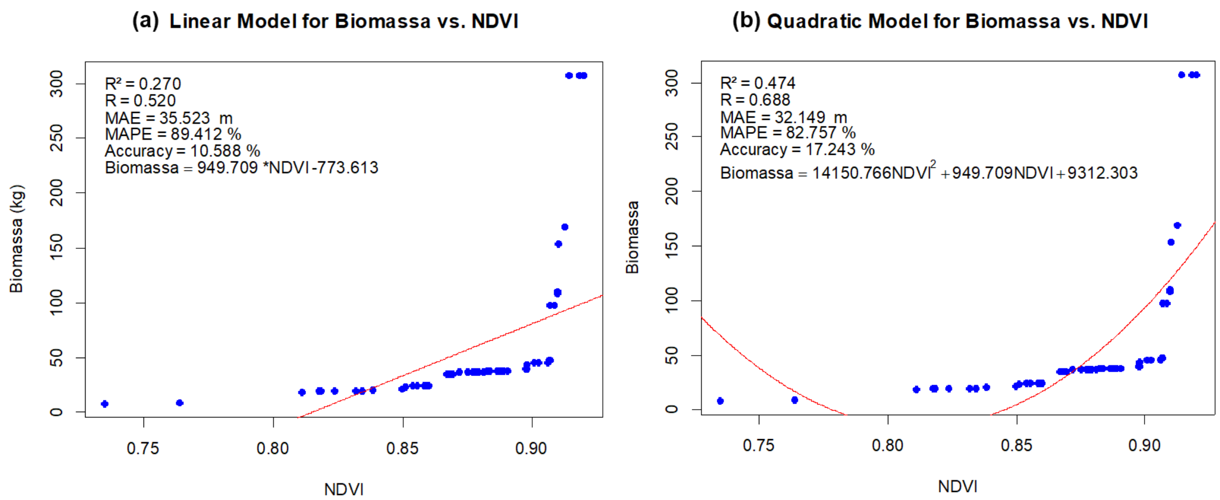
The field survey and aerial photo processing conducted yielded biomass values, carbon values, and NDVI values extracted at each point. The results indicate that older plants (planted earlier) have higher NDVI values compared to younger plants.

C. Regression Analysis

Biomass estimation from field data was conducted by calculating the diameter of plant stems derived from plant circumference. Biomass determination was performed using Equation 2. The obtained biomass was used as a variable for regression modeling with 4 schemes: linear regression, quadratic, cubic, and exponential, as shown in Figure 3. The modeling results indicated correlation values for the linear regression model at 0.52; quadratic at 0.68; cubic at 0.81; and exponential at 0.84 (details shown in Table 1).

TABLE 1. THE EQUATIONS FOR EACH REGRESSION BETWEEN BIOMASS (Y) AND NDVI.

Model	Model Regresi	Training (70%)				
		RMSE	MAPE	Accuracy	R^2	R
Linear	Y = (949.709 × NDVI) – 773.613	35.523	89.412	10.588	0.270	**0.520**
Exponential	$Y = 1.3e^{-6}$ x 316656862.6^{NDVI}	22.063	24.589	75.411	0.714	**0.845**
Cubical	$Y = -702803.869 \times NDVI^3 + 286248.011 \times NDVI^2 + 573940.147 \times NDVI - 155859.282$	26.482	69.534	30.466	0.663	**0.814**
Quadratic	$Y = 14150.766 \times (NDVI)^2 + 949.709 \times NDVI + 9312.303$	32.149	82.757	17.243	0.474	**0.688**



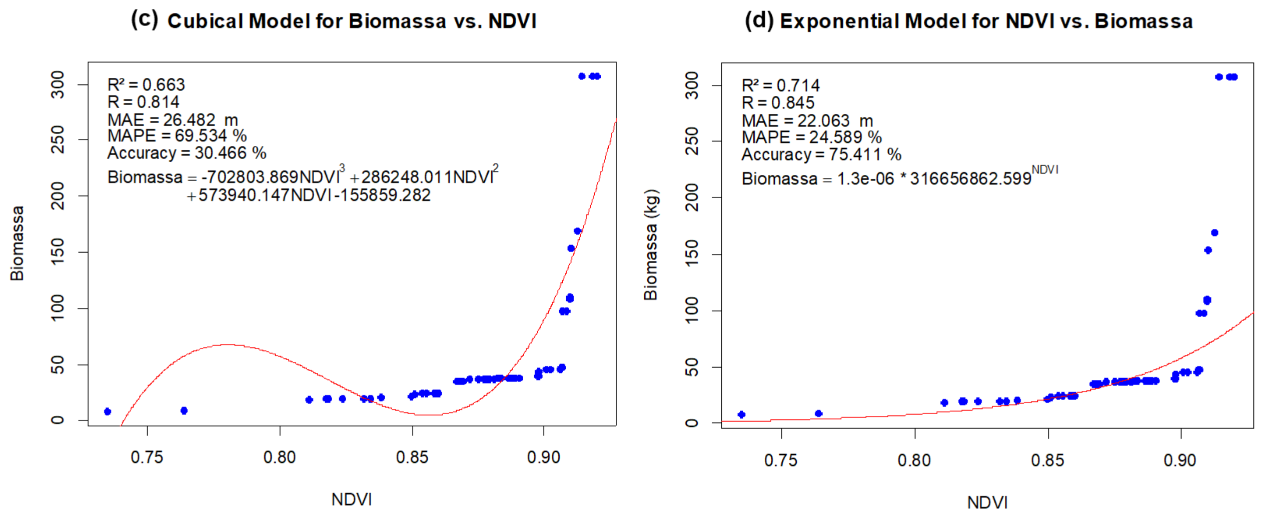


Figure 3. The models for estimating carbon stock based on NDVI and biomass.

D. Accuracy Testing and Best Fit Model Estimation

Accuracy testing is performed using the 13 sample points obtained in the field. The accuracy test is conducted by examining the RMSE between the field-measured biomass and the aerial photo results. The accuracy values obtained from the biomass estimation model and the carbon stock estimation for all regression modeling are presented in Tables 2 and 3.

TABLE 2. RMSE BETWEEN FIELD-MEASURED BIOMASS AND AERIAL PHOTO-BASED BIOMASS ESTIMATION RESULTS

No.	B_True	B_Linear	B_Exponensial	B_Cubical	B_Quadratical
1	36.79	60.03	37.58	22.54	45.57
2	172.94	94.06	75.77	165.19	130.54
3	98.28	89.71	69.27	136.91	117.66
4	43.85	80.23	56.97	86.35	91.62
5	37.64	63.87	40.67	30.61	53.34
6	24.62	45.55	27.88	6.12	20.43
7	36.79	63.10	40.03	28.85	51.75
8	35.11	52.78	32.36	11.73	32.15
9	98.19	89.39	68.81	134.94	116.72
10	24.62	34.47	22.19	5.79	5.64
11	19.51	11.11	13.71	26.66	-12.93
12	1.93	-212.72	0.14	-3065.63	677.29
13	38.50	74.11	50.23	61.17	76.33
RMSE		**3.97E+01**	**15.656**	**2.55E+02**	**72.253**
MAPE		9.08E+02	**26.82**	1.23E+04	2747.8
Accuracy		-9.07E+02	**73.18**	-1.23E+04	-2746.8
R2		0.267	**0.722**	0.143	0.014
R		0.51672043	**0.849705831**	0.378153408	0.118321596

TABLE 3. RMSE BETWEEN FIELD-MEASURED CARBON STOCK AND AERIAL PHOTO-BASED CARBON STOCK ESTIMATION RESULTS

No.	SC_True	SC_Linear	SC_Exponensial	SC_Cubical	SC_Quadratical
1	17.290	28.216	17.661	10.592	21.419
2	81.283	44.208	35.610	77.639	61.354
3	46.192	42.164	32.557	64.349	55.298
4	20.608	37.708	26.778	40.586	43.062
5	17.690	30.019	19.115	14.387	25.069
6	11.574	21.408	13.103	2.878	9.601
7	17.290	29.658	18.814	13.561	24.321
8	16.504	24.805	15.207	5.512	15.111
9	46.150	42.012	32.341	63.424	54.859
10	11.574	16.203	10.429	2.722	2.652
11	9.169	5.221	6.443	12.531	-6.075
12	0.905	-99.980	0.064	-1440.844	318.325
13	18.096	34.833	23.607	28.752	35.874
RMSE		**3.97E+01**	**15.656**	**2.55E+02**	**72.253**
MAPE		9.08E+02	**26.82**	1.23E+04	2747.8
Accuracy		-9.07E+02	**73.18**	-1.23E+04	-2746.8
R2		0.267	**0.722**	0.143	0.014
R		0.51672043	**0.849705831**	0.378153408	0.118321596

The RMSE calculation results are relatively large because the accuracy values obtained are far from the range of 0.0-1.0. The accuracy values obtained indicate a significant bias in the carbon stock estimation models constructed. This is because the carbon stock values are obtained from the calculation of allometric equations for each sample using the diameter of tree stems as the predictor, while the NDVI values only indicate the greenness or density of vegetation canopy based on the reflectance values of an image. The accuracy test results using RMSE show a significant error value, where lower RMSE values indicate more accurate estimation results. Among the four regression equation models, the most optimal one is the exponential regression model with an RMSE value of 15.65 and an accuracy rate of 73%.

E. Carbon Stock and Biomass Estimation

The biomass values obtained from the exponential regression modeling are then used to estimate carbon stock using Equation 3. The RMSE accuracy test results between biomass and carbon stock estimates are very similar, as carbon stock is derived from biomass. The regression equation from the best fit model is then applied to all pixels of the aerial photo using the NDVI raster. The NDVI results are converted into biomass and carbon stock using raster calculator (shown in Figure 4).

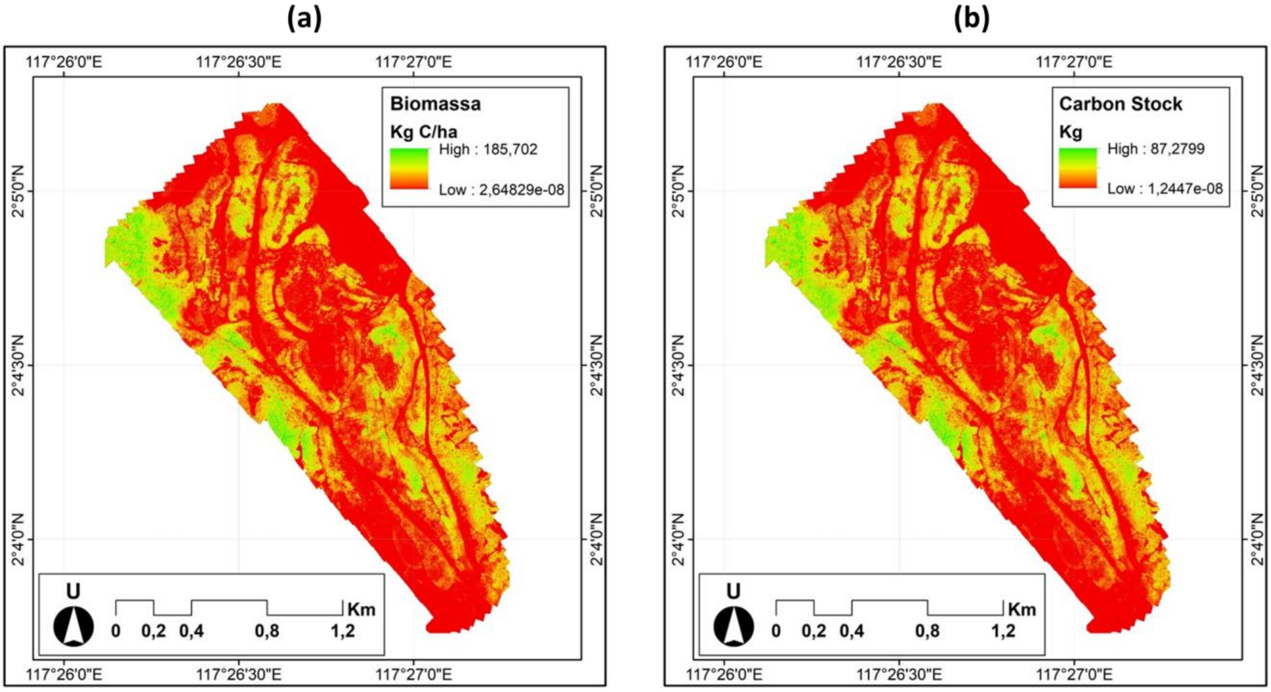


Figure 4. The Modeling Results of (a) Biomass and (b) Carbon Stock Using Aerial Photos.

TABLE 4. THE ESTIMATED BIOMASS AND CARBON STOCK RESULTS PER REVEGETATION AREA

Planting Year	Plant Age	Area (Ha)	Biomass (Kg C/Ha)	Carbon Stock (Kg)	Carbon Stock per Hectare
2015	8	26.712	4024759392.673	1891636914.634	70817156.852
2016	7	7.588	1288963847.724	605813008.452	79837036.531
2017	6	13.569	1433491589.498	673741047.077	49654443.503
2018	5	12.725	1273841204.256	598705366.012	47047989.557
2019	4	18.789	1407966733.066	661744364.565	35219578.867
2020	3	11.004	461083565.538	216709275.804	19693198.417
2021	2	9.095	606397234.526	285006700.235	31335533.541
2022	1	9.270	1058183147.413	497346079.299	53650147.880

Note: Field sampling and aerial photo data acquisition were conducted in 2023.

The biomass and carbon stock estimates are calculated for each planting area to determine the total results obtained, as shown in Table 4. The results indicate that as the age of the plants increases, the vegetation index (NDVI) of the plants will also increase, leading to a higher biomass and carbon stock content in the area. However, these results are still limited to remote sensing observations. A comparison with field data obtained through comprehensive tree measurements is needed. With a relatively high accuracy of 73%, the results of this study can be used as an effective alternative for evaluating post-mining revegetation, providing valuable insights.

IV. Conclusion

Area of post-mining land at PT Berau Coal Site Binungan in the reforestation program from 2015 to 2022 has an NDVI greenness index ranging from -0.22 to 0.99, with a dominance of relatively green NDVI indices. Processing results show that the NDVI values exhibit a positive trend with increasing plant age. Regression modeling for biomass and surface carbon stock estimation was conducted using four regression models, with the exponential regression model (1.3e-6 x 316656862.6NDVI) identified as the best fit model, with a correlation coefficient of 0.84. This correlation value falls within the category of relatively high correlation. The RMSE generated in the accuracy testing was 15.65, with an accuracy rate of 73%. The carbon stock values for each planting year were obtained as follows: 70,817,156.852 Kg/Ha in 2015, 79,837,036.531 Kg/Ha in 2016, 49,654,443.503 Kg/Ha in 2017, 47,047,989.557 Kg/Ha in 2018, 35,219,578.867 Kg/Ha in 2019, 19,693,198.417 Kg/Ha in 2020, 31,335,533.541 Kg/Ha in 2021, and 31,335,533.541 Kg/Ha in 2022. The modeling results indicate a tendency for an increase, attributed to the development of stem allometry diameter, which increases each year, consequently boosting the carbon stock quantity. To enhance accuracy, further research could involve increasing the number of sample points and calculating plant canopy factors.

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