Estimation of Mangrove Canopy Cover Using Unmanned Aerial Vehicle (UAV) in Indramayu Regency, West Java

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Abstract. Mangrove forests are an essential natural resource in coastal environments and have three main functions: physical, biological, and economic. Indramayu regency is one of the areas on the north coast of Java with a coastline length of 147 km. The decrease of mangrove canopy in Indramayu regency cannot be separated from the land clearing for a fish pond. Therefore, monitoring activity is important to see the mangroves sustainability management. An alternative way to monitor mangrove conditions is using an unmanned aerial vehicles (UAV) to overcome the budget constraint and difficulties of doing field surveys. The study aims to estimate the mangrove canopy cover based on the NDVI derived from unmanned aerial vehicles (UAV). The research was conducted in Indramayu in March 2021. Data collection was conducted using unmanned aerial vehicles (UAV) with multispectral sensors. The study shows that the best canopy cover estimator model is exponential regression with the equation of $CC = 0.1535e^{1.9458\text{NDVI}}$ and $R^2 = 0.636$. The model can be used for monitoring mangroves periodically. Accurate monitoring data will be very useful in preparing policies and management strategies to maintain and improve the functions and services of the mangrove ecosystem.

1. Introduction
Mangrove is an intertidal plant found along tropical and non-tropical coastlines [1]. Mangrove canopy plays a significant role in maintaining coastal ecosystems. These roles include physical, biological, and economical functions. Physical functions include maintaining the stability of the coastline, protecting the coast from erosion or sea abrasion and seawater intrusion, holding and storing mud, and filtering polluted materials. Its biological function provides ideal breeding grounds for much of the world's fish, shrimp, crabs, and other shellfish. In addition, economically, it functions to provide fuel, cultivation, pond, and building materials. Because of its significant role in maintaining the coastal area, the ability to measure and estimate mangrove canopy cover is the key to understanding and assessing the physical condition of mangrove sustainability.

Canopy cover is one of the crucial parameters of forest structure for many applications in ecology, hydrology, and forest management. It is defined as an area of land covered by vertical projections of canopies, which describes its structural conditions [2]. The measurement of a canopy cover is currently considered necessary in forest inventories and can use the application of hemispherical photography [3]. Hemispherical photography is a photography method used to see the forest canopy cover through photos with a camera. It is an advantageous method because of its easy usage, lower costs, and more accurate
results. However, this approach has significant obstacles, namely that it cannot cover an extensive mangrove area and its acquisition is time-consuming. Therefore, other methods will be needed to replace it.

One of the newest technologies to monitor mangrove canopy cover is an unmanned aerial vehicles (UAV) equipped with a multispectral camera. UAV has optical sensors that can provide more detailed images with high resolution. Furthermore, its application can become a solution for tropical countries like Indonesia because the biggest obstacle in using satellite technology is cloud coverage, fog, and smoke [4]. The development of drone technology is extensively implemented in small-scale forest inventories because of its benefits, low costs, and high flexibility [5]. This approach is an alternative to determine the mangrove canopy cover. Based on the explanation, drone-supported research is needed to see the mangrove canopy cover in Indramayu regency, West Java. UAV is considered superior to satellite imagery because the data obtained are high resolution and free from clouds. The study aims to estimate the mangrove canopy cover based on the NDVI derived from unmanned aerial vehicles (UAV). The application of UAV is expected to provide accurate information on mangrove canopy cover in Indramayu regency, West Java.

2. Data and Methods

2.1. Location
This research was carried out in Indramayu regency, West Java (figure 1), which, astronomically, is located at E 107°52’ – S 108°36’ BT dan S6°15’ - S6°40’ with an elevation range of 0.5 to 1.5 m above the sea level. The area of data collection is focused on the mangrove areas in 3 villages, namely Karangsong village and Pabean udik village in Indramayu sub-district and Cemara village in Losarang sub-district. Mangrove species commonly found in the data retrieval locations are *Rhizophora mucronata* and *Avicennia marina*.

![Figure 1. Maps.](image_url)

2.2. Data
The types of data used in this study are primary and secondary. The primary data taken are multispectral drone-based imagery and mangrove canopy cover field. Meanwhile, secondary data were retrieved from the internet as supporting data. Multispectral drone-based imagery was obtained from the flight results using unmanned aerial vehicles (UAV) that had been installed with multispectral sensors. The UAV was flown at an altitude of 100 m, with side laps and end laps of 70 – 80%, and images were captured in intervals of 2 s/photos. As this study did not use ground checks points (GCP), positioning was only
based on the coordinate information on the image obtained. Afterward, multispectral imagery data were processed in the *Pix4DMapper* software with a multispectral agriculture template. The output generated from the *Pix4dmapper* software was an index, which was then classified into several vegetation cover classes with normalized difference vegetation index (NDVI) and the equation:

$$\text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}}$$

(1)

note: NIR=NIR spectral reflectance;RED: RED spectral reflectance

Mangrove canopy cover field data were obtained from the canopy shooting with the use of a lens at an angle of 180°, or also known as the hemispherical photograph method. When taking photos, the camera must be placed at the height of ±1 m and positioned facing north [6]. The time for taking photos was in the afternoon or when the atmosphere was cloudy. This was intended to reduce the diffraction of sunlight, which resulting in shaded-looking photos that are difficult to analyze [7]. The approach of this method on canopy cover used canopy cover index (CC) [8], which is proved to be precise for estimating canopy cover, comparable to visual canopy cover estimation, and unaffected by observer bias [8]. The data for canopy cover index (CC) had 48 photos that was taken in 48 plots in mangrove vegetation for further analyzing. When estimating the canopy cover index, the canopy was photographed while the camera was kept in a vertical position. The digital or scanned camera images were then converted into binary images so that the canopy and the sky were shown in different colors; commonly, the canopy is shown in black, while the sky is in white. Next, the percentage of black and white pixels in the binary image can be calculated (6). The calculation of canopy cover index (CC) used the *Hemiview* 2.1 software (Delta-D Devices, UK) to convert the photos into binary images. Subsequently, the black and white pixels in the binary image were then calculated with supervised classification using *ArcGIS* 10.5.

2.3. Building regression model

The regression model was used in the canopy cover equation, with canopy cover index (CC) as the dependent variable and NDVI as the independent variable. Before implementing the regression analysis, there was a requirement that must be fulfilled for further analysis. Classic assumption is needed before developing the regression model. The classic assumption used in this study is normality and heteroscedasticity. Therefore, the normality was tested using the Kolmogorov-Smirnov test and showed a 0.2 normality, which signifies a P-Value (Kolmogorov-Smirnov) of > 0.05. The heteroscedasticity test is applied to determine whether there are differences in residual variance from one observation to another [9], which is performed by employing the application of the Glejser Test. Based on the heteroscedasticity test carried out using Glejset, it produced a significance value of 0.641. The test decision is conducted when the significance value between the dependent variable and the residual value (Sig) is higher than 0.05 [9]. This indicates that the data are shown to be normal, with no heteroscedasticity found in them.

Mangrove canopy cover field data were divided into two parts, 33 data for modeling and 15 for accuracy assessment. The canopy cover estimation model was prepared using the equation models as shown in equation (2-5).

- Linear : $Y = a + bx$  \hspace{1cm} (2)
- Exponential : $Y = ae^{bx}$ \hspace{1cm} (3)
- Quadratic : $Y = a + bx + cx^2$ \hspace{1cm} (4)
- Logarithmic : $Y = ax^b$ \hspace{1cm} (5)

note: $y=$canopy cover index (CC); and $x=\text{NDVI}$
After building the regression model, validation was needed to know the accuracy of the model made. Validation testing was calculated using bias (e), aggregate deviation (SA), average deviation (SR), and root mean square error (RMSE) with the formula as shown in the equation below (6-9).

\[
e = \frac{\sum_{i=1}^{n} (y_i' - y_i)}{n} \times 100\%
\]

\[
SA = \frac{\sum_{i=1}^{n} y_i' - \sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} y_i'}
\]

\[
SR = \left(\frac{\sum_{i=1}^{n} y_i' - y_i}{n}\right) \times 100\%
\]

\[
RMSE = \left(\frac{\sum_{i=1}^{n} (y_i' - y_i)^2}{n}\right)^{\frac{1}{2}} \times 100\%
\]

Note: \(y'\) : prediction value; \(y\) : actual value

2.4. Selection best fit model
Following the model validation, selecting the best regression model was carried out by ranking the comparator values (R2, SA, SR, RMSE, e). The best model has the highest scoring value. The scoring formula used is shown in the equation below (10).

\[
Score = \left(\frac{NU - \min_i}{\max_i - \min_i}\right) \times (n - 1) + 1
\]

Note: \(NU\) = Correlation value; \(\max_i\) = Max correlation value; \(\min_i\) = Min correlation value; \(n\) = total of model

3. Results and discussion

3.1. NDVI results
The canopy cover model is established from the regression equation between the canopy cover index (CC) and the NDVI value. The results of an image that was processed with multispectral-based drone imagery showed that the NDVI imagery exhibited a clear appearance of water, soil, and vegetation in the study area. Figure 2 presents the appearance of water that is shown in low NDVI values (red color), while the appearance of vegetation is shown in high NDVI values (green color). The NDVI transformation have a reliable ability to distinguish objects in identifying vegetation density, assuming that the higher canopy density also has a higher NDVI value.
Figure 2. NDVI maps (a) Karangsong village (b) Pabean udik village (c) Cemara village.

The NDVI values found in three locations each has a different range. In Karangsong Beach, the NDVI value has a range of -0.84501 to 0.941243. The NDVI value in Pabeanudik has a range of -0.61816 to 0.957496. Meanwhile, the NDVI value in Cemara Village, Losarang Subdistrict has a range of -0.501358 to 0.930176. NDVI has a range of values ranging from -1 to 1 where a value of -1 to 0 indicates a non-vegetation object while a value of 0 to 1 indicates the absence of vegetation objects. NDVI values in the range of 0 to -1 indicate objects of reflection from soil, mud, or water [10]. Furthermore, NDVI is commonly used for vegetation monitoring as it has the suitability to map various mangrove features, such as vegetation cover type, vegetation formation or community, doubletree crown or larger gaps, singletree crown, canopy gaps, foliage clumping, and single shrub crown in various pixel size with the maximum of 10m [11].

3.2. Canopy cover index (CC) results
Canopy cover is the perpendicular projection of tree crowns onto a horizontal surface [8]. Estimation of canopy cover by visual observation is commonly used for the description of vegetation structure in vegetation science and forest ecology. Each plot was represented by a hemispherical photo and then analyzed into one canopy cover index (CC). In this study, 48 canopy cover indexes (CC) were grouped according to the density class from the map that had been created. The range of values generated from the retrieval with hemispherical photography ranged from 0.217 to 0.959. The high canopy cover index (CC) was caused by the tight area of the tree header, blocking the sun’s radiation from entering and hitting the surface of the observation site. The cause of the small canopy cover index (CC) value in this study was because, at the time of shooting at the observation site, there was no sign of growing mangrove vegetation or dying vegetation; therefore, no canopy cover was photographed. The greater the canopy cover index (CC), the wider the leaf surface, and the greater the ability to cover the ground can result in received solar radiation and lower ground level.

3.3. Estimating model using regression analysis
Regression analysis was performed to determine the relationship between the independent and the dependent variable. Furthermore, the independent variable was the NDVI, while the dependent was the canopy cover from the canopy cover index (CC) in table 1.

The results of the canopy cover estimation using NDVI values in the field showed the best estimator model with a value of $R = 0.797$ and $R^2 = 0.636$ obtained from the exponential model $CC = 0.1535 e^{1.9458 \times NDVI}$. The exponential regression model could expect a canopy cover index of 63.6% while the rest was influenced by other variables. The coefficient of determination ($R^2$) showed the ability of the independent variables to explain the dependent variable. The higher $R^2$ in the regression equation model indicates that the free variable is better in describing bound variables [12]. The R-value explains
the magnitude of the correlation value between the NDVI result and the canopy cover index. These two possess a quite intense relationship. The F-Test is used to determine the meaning of the role of a free variable against its bound variable. All regression models had a calculated F actual > F table at a real level of 5%. This indicated that at a confidence level of 95%, there was an influence of free variables, i.e., NDVI values, on bound variables, i.e., canopy cover index (CC). From the resulting output, it could be known that the calculated F Actual of 36,157, with a significant rate of 0.000 < 0.005, was higher than the F Table of 4,160. This means that the regression model can be used to predict the participation variable [13]. The vegetation index analyzed through remote sensing is already used to provide information on the biophysical status of plants. Generally, the bands used in relation to biomass, canopy structure, header cover, and Leaf Area Index are NIR and RED bands. The exponential model is a model used to assume the relationship between biophysical parameters and vegetation index. This model is the same as the results of this study, which show that the best canopy cover estimation model that can be used is the exponential model. The regression curve can be seen in figure 3.

Table 1. Canopy cover model equation.

| Code | Model    | Equation                                      | R²    | S        | F Actual | F Table |
|------|----------|-----------------------------------------------|-------|----------|----------|---------|
| M1   | Linear   | CC = 1.168NDVI – 0.186                         | 0.538 | 0.104    | 36.157   | 4.160   |
| M2   | Exponential | CC = 0.1535e1.9458NDVI                        | 0.636 | 0.103    | 54.109   | 4.160   |
| M3   | Logarithmic | CC = 0.815ln(NDVI) + 0.9382                    | 0.545 | 0.105    | 37.106   | 4.160   |
| M4   | Quadratic | CC = -1.0567NDVI² + 2.6748NDVI – 0.7042        | 0.545 | 0.105    | 17.999   | 4.160   |

Figure 3. Regression model curve (a) Linear (b) Exponential (c) Quadratic (d) Logarithmic.

Model validation is needed to see the model's ability to suspect a new group of data with a relatively similar state to the state of the data used to form its model [15]. Model validation can be proven from several indicators; namely, aggregate deviation (SA), average deviation (SR), bias (e), and root means square error (RMSE) presented in table 2.
Table 2. Validation model.

| Code | Model      | Equation                                       | Validation indicator |
|------|------------|-----------------------------------------------|----------------------|
|      |            |                                               | SA       | SR (%)  | RMSE (%) | e (%)  |
| M1   | Linear     | CC = 1.168NDVI - 0.186                         | 0.3733  | 0.379   | 0.406    | 0.29443|
| M2   | Exponential| CC = 0.1535e1.9458NDVI                        | 0.3734  | 0.368   | 0.401    | 0.28750|
| M3   | Logarithmic| CC = 0.815ln(NDVI) + 0.9382                   | 0.3736  | 0.379   | 0.407    | 0.29485|
| M4   | Quadratic  | CC = -1.0567NDVI2 + 2.6748NDVI – 0.7042       | 0.3737  | 0.379   | 0.407    | 0.29500|

Based on the validation test, the aggregate deviation (SA) obtained by all models ranges from 0.3733 to 0.3737, which is still in the values range of -1 to 1. Good aggregate deviation values range from -1 to 1. [16]. Aggregate deviation values represent the validity values of the model. The smaller the value obtained, the higher the model validity is because the difference in the alleged value to the actual value will be smaller. A good model if the average deviation (SR) of less than 10% [15]. The preparation of a regression equation model that uses one change is allowed to have a maximum bias of 25% [17]. The model validation test results showed that all models created could meet these criteria with the bias values of 0.28750% to 0.29500%.

Root mean square error (RMSE) is one of the most commonly used indicators in regression. The validation test results in Table 4 show that the RMSE values range from 0.401% to 0.407%. Root Mean Square Error (RMSE) is an indicator that explains the proximity of the expected value and the actual value in the field. Based on research, RMSE is a metric that is commonly used to measure errors in the climate and environment [18]. The smaller the RMSE value, the better the equation model that can be produced [19]. All criteria in the validation test show that all models made are of good quality because they meet the required criteria.

3.4. Best selection model

The best model was selected based on its score using aggregate deviation (SA), average deviation (SR), bias (e), and root means square error (RMSE) correlation criteria and aggregate deviation values. The best model has the highest scoring. The results of the scoring are presented in Table 3.

Table 3. Scoring result.

| Code | Model      | Scoring | Total | Ranking |
|------|------------|---------|-------|---------|
|      |            | R²      | SA    | SR      | RMSE    | e       |       |
| M1   | Linear     | 4.00    | 4.00  | 1.02    | 1.37    | 1.23    | 11.62  | 2      |
| M2   | Exponential| 1.00    | 3.23  | 4.00    | 4.00    | 4.00    | 16.23  | 1      |
| M3   | Logarithmic| 3.79    | 1.81  | 1.00    | 1.00    | 1.06    | 8.66   | 3      |
| M4   | Quadratic  | 3.79    | 1.00  | 0.98    | 0.88    | 1.00    | 7.65   | 4      |

Table 3 shows that the best canopy cover estimation model is the M2 model with the exponential regression type, with the highest score compared to the other models. The equation of M2 is $CC = 0.1535e^{1.9458NDVI}$ with $R^2$ of 0.636; this signifies that the exponential model can estimate the mangrove canopy cover by 63.6%. The exponential model also had the smallest validation test value among other models with an SA value of 0.374, SR of 0.368%, RMSE of 0.401%, and a bias index of 0.28750%, indicating that this model has the lowest error rate in predicting values.

3.5. The study implication for protecting coastal area

Mangrove monitoring activities are critical affairs, particularly in coastal areas, to see its sustainability management. With its status as one of the fragile ecosystems, mangrove requires continuous monitoring
to detect threats, including human activities, pollution, over-grazing, disease, fire, storms, and desiccation. A monitoring system is also needed for mangrove plantations as it provides empirical data for measuring the rate of growth and identifying areas require remedial attention. This study aims to see mangrove canopy cover and determine the status of mangrove forest conditions in certain regions. Regular monitoring is also required to prepare management policies and strategies to maintain and improve the functions and services of mangrove ecosystems [20]. Based on data from the Environmental Agency (Dinas Lingkungan Hidup) in 2017, the coastal area of Indramayu regency covers 28,424.31 ha and is spread over 11 sub-districts with a total of 41 villages. The Pasekan sub-district is a sub-district with the largest protected area that consists of 5,584.73 ha (19.65%). Meanwhile, the Karangampel sub-district is the sub-district with the smallest protected land, consisting of 708.81 ha (2.49%) out of a total [21]. Land cover conditions are relatively low; therefore, the function of protection is also reduced.

Mangrove ecosystems, especially on small islands, are identical to the heavy muddy terrain, dense vegetation, and habitat of reptiles estuary river. These factors may turn into obstacles in accessing and managing the mangrove forest. Furthermore, this also impacts the effectiveness of time and energy, and safety aspects when monitoring due to the relatively large travel load [22]. One effective method to circumvent this shortcoming is by using remotely sensed imagery data, which offers a more accurate way of measuring the ecosystem and a more efficient tool for managing the mangrove forest. By using the model that has been created, mangrove monitoring can be conducted periodically using unmanned aerial vehicle (UAV) for the acquisition of biophysical parameters such as canopy cover. The availability of accurate data is a key in implementing management strategies of the mangrove ecosystem that include the synergy and cooperation of cross-sectoral institutions, simultaneous actions of creating national documents, strengthening mangrove ecosystem protection policy, improving the capacity of human resources in the region, and environmental development.

4. Conclusion

The best regression model to estimate canopy cover that applies the use of multispectral drone-based imagery in Indramayu regency, West Java, is the exponential model with the equation of CC = 0.1535e1.9458NDVI with $R^2 = 0.636$, which signifies that 63.6% can predict dependent variables (CC). The model also has the smallest validation test value among other models with an SA value of 0.374, SR of 0.368%, RMSE of 0.401%, and a bias of 0.28750%.

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