Above-ground biomass estimation of mangrove forest using WorldView-2 imagery in Perancak Estuary, Bali

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Abstract. Global warming is the important issues because is caused by the concentration increase of greenhouse gasses in the atmosphere. Mangrove ecosystem has a function to reduce climate change through carbon sequestration. Estimates of biomass can be done through an approach from the value of vegetation biomass. Allometric equations method is used for calculating biomass values. Remote sensing technology is used for mapping mangrove ecosystems to determine the spatial distribution of mangrove biomass that is WorldView-2 (WV-2) image. Transformation of the vegetation index arc Normalized Difference Vegetation Index (NDVI) and Soil Adjusted Vegetation Index (SAVI) are used to estimate of mangrove forest biomass. The aim of this study is to determine the most accurate vegetation index in estimating the mangrove above-ground biomass (AGB) value. The field biomass data was obtained from mangrove tree diameter at breast height (DBH) measurement. Using the allometric equation, the field AGB can be calculated. A regression analysis between field biomass and WV-2 image pixel value was performed to build regression function to estimate the mangrove AGB. The results of this study show that the SAVI provided higher accuracy for mangrove AGB estimation with \( R^2 \) of 0.4125 and resulting the AGB value between 1124.81 to 4499.25 kg/m.

1. Introduction
Global warming is one of the important issues because it can affect human life and environmental damage. Global warming is caused by the concentration increase of greenhouse gasses in the atmosphere and causes by the increase of surface temperature [1]. The increase in the surface temperature causes climate change such as sea-level rise, rainfall patterns changes, displacement of evaporation in the air, and air pressure that will change the climate pattern in the world [2]. Reducing CO₂ emissions through forest vegetation is very necessary. Mangrove ecosystems have a function to reduce climate change because it can reduce CO₂ through "sequestration", where carbon in the atmosphere and its storage in compartments such as plants, soil materials and organic matter [3]. The absorption of carbon emissions by mangrove forests will reduce the impact of global warming and climate change that occur on the surface. Mangrove forests included in coastal conservation has functions and roles, both from physical, ecological, economic and mitigation functions in the process of CO₂ absorption and storing them in the form of tree biomass [4]. Most of the carbon stored in mangroves is stored in sediments, surface biomass and underground biomass [5].

Perancak Estuary has mangrove forests with an area of 177.09 ha which is a large forest area after it was altered to become fishpond area in 1980 [6]. Estimates of Above-Ground Biomass (AGB) can be done through the relationship between field vegetation AGB and image pixel value at the corresponding position [7]. The WorldView-2 image is used in estimating the mangrove forest carbon stock because it has a high spatial resolution of 1.84 m using 8 multispectral bands. The transformation of the vegetation index used is Normalized Difference Vegetation Index (NDVI) and Soil Adjusted Vegetation Index (SAVI). The use of these different vegetation indices aimed to figure out the level of estimation accuracy and determine an accurate vegetation index in calculating the mangrove forest AGB.
Therefore, the aim of this study is to determine the most accurate vegetation index in estimating the mangrove Above-Ground Biomass (AGB) value.

2. Methods

2.1. Research site
The study was conducted at Perancak Estuary in Jembrana Regency, Bali Province with the coordinates of the study locations 238000 - 239000 mT and 9071000 - 9072500 mU (UTM zone of 50M) presented in Figure 1. Mangrove forests in this area have an area of 178.6 ha [8]. Mangroves in this area have a variety of types and are located along the river estuary which is still affected by the tides. According to Sidik et al. [9], Perancak Estuary, Bali has 17 major mangroves species including *Avicennia alba*, *Avicennia marina*, *Avicennia officinalis*, *Bruguiera cylindrica*, *Bruguiera gymnorrhiza*, *Rhizophora apiculata*, *Rhizophora mucronata*, *Rhizophora stylosa*, *Ceriops tagal*, *Ceriops decandra*, *Exoecaria agallocha*, *Lumnitzera racemosa*, *Sonneratia alba*, *Nypa fruticans*, and *Xylocarpus granatum*.

![Figure 1. Research location in Estuary Perancak, Bali (WV-2 532 image composition).](image)

2.2. Image data
The data used for this study is WorldView-2 image obtained from the Digital Globe Foundation acquired on September 18th, 2018. It has eight multispectral bands includes coastal blue (400–450nm), blue (450–510nm), green (510–580nm), yellow (585–625nm), red (630–690nm), red edge (705–745nm),
NIR1 (770–895nm), and NIR2 (860–1040nm). No further geometric correction needed for this image, because has been geometrically corrected up to 2A level. Radiometric correction is needed to convert image pixel value in digital number to top of atmosphere reflectance. To obtain the reflectance value of the object on the ground, further atmospheric correction is conducted using the Dark Object Subtraction (DOS) method by using spectrally darkest objects such as deep, calm, and clear water on the image.

2.3. Field data acquisition
Field campaign was carried out between 4th to 10th of April 2019 in Perancak Estuary, Bali. A total of thirty 2 x 2 meters plots was obtained during the field campaign. The field sample plots were located by purposive sampling taking into account accessibility, diversity and density of mangroves, hue or color in WV-2 images. Within each sampling plot, four data were collected; location of the plot center, diameter of mangrove trees at breast height (DBH), tree canopy height, and dominant mangrove species. The center of plot location was measured using Global Navigation Satellite System (GNSS) receiver with average location reading of about 3-5 minutes to minimize the reading obstruction under the thee canopy. The DBH was measured for each tree stems found within the plot using tape meter following the procedure from BSN [7] (Figure 2a). The average mangrove canopy height (Figure 2b) within the plot was measured using laser range finder and the dominant mangrove species found in the plot was identified. The mangrove above-ground biomass was then calculated using allometric equation for each mangrove species using field DBH data.

![Figure 2. Field measurement of (a) DBH and (b) tree canopy height.](image)

2.4. Calculation of Field AGB
The field mangrove AGB value was calculated using allometric equations for each mangrove species following the equation of Komiyama et al [10] as presented in equation 1. This allometric approach is a non-destructive method of calculating AGB. The wood density of each mangrove species for AGB calculation is provided by [11] (Table 1).

\[
W_{\text{top}} = 0.251\rho \ DBH^{2.46}
\]

where:

- \( W_{\text{top}} \) = above-ground biomass (kg)

\[\text{(1)}\]
\[ \rho \] = wood density of each species

\[ \text{DBH} \] = diameter at breast height

### Table 1. Mangrove Wood Density each Species

| No. | Species                | Wood density (g cm\(^{-3}\)) |
|-----|------------------------|-------------------------------|
| 1.  | Avicennia alba         | 0.587                         |
| 2.  | Avicennia marina       | 0.67                          |
| 3.  | Bruguiera gymnorrhiza  | 0.764                         |
| 4.  | Bruguiera parviflora   | 0.772                         |
| 5.  | Ceriops tagal          | 0.837                         |
| 6.  | Lumnitzera racemosa    | 0.880                         |
| 7.  | Sonneratia alba        | 0.509                         |
| 8.  | Sonneratia ovala       | 0.370                         |
| 9.  | Rhizophora apiculata   | 0.843                         |
| 10. | Rhizophora mucronata   | 0.814                         |
| 11. | Rhizophora stylosa     | 1.040                         |
| 12. | Xylocarpus granatum    | 0.851                         |

### 2.5. Vegetation Index Transformation

The transformation of the vegetation indices used are Normalized Difference Vegetation Index (NDVI) and Soil Adjusted Vegetation Index (SAVI). Following is the vegetation indices equation used in this study (Table 2).

### Table 2. List of Vegetation Index Formulation

| Index                                      | Formulation                                      | Reference          |
|--------------------------------------------|--------------------------------------------------|--------------------|
| Normalized Difference Vegetation Index     | \( \frac{\text{NIR}-\text{Red}}{\text{NIR}+\text{Red}} \) | Tucker (1986) [12] |
| (NDVI)                                     | \text{NIR} = Near Infrared 1 (band 7)            |                    |
|                                            | \text{Red} = Red band (band 5)                   |                    |
| Soil Adjusted Vegetation Index             | \( \frac{((\text{NIR}-\text{Red})/(\text{NIR}+\text{Red}+L)) \times (1+L)}{L} \) | Huete (1988) [13]  |
| (SAVI)                                     | \text{L} = first order (L= 0.5)                  |                    |

### 2.6. Statistical analysis

Statistical analysis used is correlation and regression analysis. The correlation between the two variables can be described in the regression line, the line can be a straight line (linear) or curved (non-linear). The number of samples used to do the regression were 18 field samples. The biomass value that has been obtained will be regressed with both vegetation index transformations. Correlation value generated from the regression analysis, shows the strength and weakness of the field data biomass value and vegetation index value. Regression analysis produces the most accurate vegetation index, which will then be used to estimate the value of AGB which will produce a map of the spatial distribution of AGB.
3. Results and Discussion

3.1. AGB modeling with vegetation index

AGB modeling using vegetation indices transformations was done to see the relationship between the two variables (field AGB and vegetation index pixel value). The SAVI vegetation index transformation results in a linear relationship with the field AGB value where the coefficient of determination ($R^2$) is 0.4125 (Figure 3) and the transformation of the NDVI vegetation index with field biomass values has a determination coefficient ($R^2$) of 0.2556 (Figure 4). The highest value of coefficient of determination ($R^2$) will be used to produce image-based AGB map using the regression function equation. We found that SAVI have higher $R^2$ value and therefore will be used to produce AGB map.

![Figure 3. Regression of the SAVI and field AGB.](image1)

![Figure 4. Regression of the NDVI and field AGB.](image2)

Calculation of AGB values was carried out for each 30 samples that have been obtained in the field. Allometric equations used in this study refers to the formula that has been developed by Komiyama et al. [10] to obtain AGB values from a tree. Samples used for regression is as many as 18 field samples. Regression is done to determine the relationship between the two variables. The field biomass values that have been obtained will be regressed with the vegetation index transformation which will produce the most accurate vegetation index to be used in estimating the mangrove AGB. The most accurate vegetation index produced in this study in estimating AGB value is the Soil Adjusted Vegetation Index (SAVI) vegetation index because it produces a correlation value and a higher coefficient of determination than the NDVI vegetation index. The results of this study indicate that the coefficient of determination ($R^2$) of the NDVI vegetation index is 0.2556 and the correlation value ($r$) is 0.505.
The equation produced in the SAVI vegetation index regression with field biomass values will be used to produce an image that shows the distribution of AGB. The equation used is \( y = 11163x - 2916.6 \). Furthermore, the equation produced from the regression on the SAVI vegetation index will be used for the processing which will produce estimates of mangrove forest AGB from the WorldView-2 image. The range of above-ground biomass values obtained from image processing using the SAVI vegetation index varies between 1124.81 - 4499.25 kg/m\(^2\) (Figure 5), where the range of values obtained is the lowest and highest value range resulting from the calculation of the biomass value of mangrove forests.

![Image 5. Image-based AGB results from SAVI.](image)

Furthermore, the equation generated from the regression in the SAVI vegetation index will be used for the processing which will produce an estimated value of mangrove forest biomass in WorldView-2 Imagery (Figure 5). The minimum value produced on the statistical value of the SAVI vegetation index biomass is 4.079 while the maximum value is 4499.25 and the mean value is 1738.81. Figure 1. Showing that in the northern part the biomass value is quite high compared to other regions with a range of AGB values 2000 - 3000 kg/m\(^2\). This high AGB value can be caused by the area is a type of mangrove planted, so that it can be caused by a fairly spaced planting distance.

3.2. AGB Estimation Accuracy
Accuracy tests are conducted to determine the accuracy of the mapping of AGB estimates. The method used to test the accuracy is the Standard Error of Estimate (SEE) method [14]. The accuracy test phase uses sample data taken in the field for AGB with data from AGB estimation using a vegetation index.
transformation. The accuracy of the SAVI vegetation index was 42.71% and the accuracy of the NDVI vegetation index was 37.79%. The best vegetation index used in subsequent processing is the SAVI vegetation index because the SAVI vegetation index is a vegetation index that increases the sensitivity of the spectral reflection of vegetation objects by minimizing the influence of background soil conditions [15].

4. Conclusion
The results of this study showed that the coefficient of determination ($R^2$) was 0.4125 and the correlation value (r) between the transformation of the SAVI vegetation index with a field biomass value of 0.642. The most accurate vegetation index used in estimating the above-ground biomass (AGB) value of mangrove forests is Soil Adjusted Vegetation Index (SAVI). The accuracy obtained from mapping the estimated above-ground biomass is 42.71% with an estimated total AGB mapped at 301723.11 kg/m² using the SAVI vegetation index in area 178.6 ha.

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