The effect of using different vegetation indices for mangrove leaf area index modelling

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Abstract. Spectral vegetation index (SVI) is a mathematical combination of image spectral bands, especially ranges from visible to near infrared portion of the light spectrum. The purpose of SVI is to emphasize the vegetation content information from an image and doesn’t directly correlate with any physical or bio-physical characteristics of vegetation. One of the important biophysical parameters of vegetation that can be derived from SVI is Leaf Area Index (LAI). LAI can be defined as one half the total green leaf area per unit horizontal ground surface area and considered as an indicator to determine the level of mangrove health. Various SVIs have been developed and different SVI affects the accuracy of the LAI model. This study aimed to (1) compare and contrast the performance of several SVIs applied to WorldView-2 (WV-2) image to estimate the LAI, and (2) find the most accurate model for estimating LAI of mangrove forest in Perancak Estuary, Bali. The SVI used are Simple Ratio (SR), Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Green Atmospherically Resistant Vegetation Index (GARI), dan Wide Dynamic Range Vegetation Index (WDRVI). The LAI models developed were based on the semi-empirical relationships between SVIs and field LAI measured from hemispherical photograph. The corresponding values of both parameters were correlated to find the regression function for the modelling. The results show that the best accuracy was obtained from NDVI which has an $R^2$ value of 0.83 and an estimation accuracy of 89.10%.

1. Introduction

The spectral vegetation index (SVI) is a mathematical combination of image spectral bands, especially from visible to near infrared portion of the light spectrum. The purpose of using SVI is to extract information that contains spectral reflectance values from the characteristics of vegetation and minimize the spectral reflectance values of the soil, atmosphere, and geometric effects [1]. The application of the SVI has been carried out at the leaf scale range to the global level. Several have been carried out on different vegetation [2]. Some of SVIs has the advantage of extracting information related to vegetation cover and canopy from remote sensing images, which is due to its ease of representing the process and analysis of data obtained from satellites [3]. This optical remote sensing tool has the ability to carry out a long-term monitoring process through vegetation biophysical parameters. SVIs related to the broadband greenness of vegetation. This SVIs are the effective measures of the values of green vegetation and biophysical parameters. They are patterns of reflectance that are sensitive to the values of foliage chlorophyll concentration, canopy leaf area, foliage clumping, and canopy architecture. The broad correlations have been found between the broadband greenness SVIs and canopy. SVI analysis can measure the biophysical parameters of vegetation through spectral reflections. Spectral reflectance of vegetation objects is illustrated through the spectral characteristics of two wavelengths, namely red and near-infrared (NIR) bands. In red band (630-690 nm), chlorophyll is absorbed. On the other hand,
in the NIR band (770-895 nm), a strong reflection process occurs due to the structure of the leaves. The contrast of the two bands creates a good response to the characteristics of vegetation reflection values and can be related to biophysical aspects. One type of vegetation that can be tested for aspects and biophysical parameters is mangrove vegetation. Mangroves grow in transitional habitats on land and sea. This causes the emergence of three main features that can be recorded by remote sensing, namely the composition of pixels between water objects, soil, and vegetation which affect the spectral reflection characteristics of mangrove vegetation [4]. Analysis of vegetation index related to mangrove biophysical parameters became very interesting and relevant to be carried out in this study. One of the mangrove biophysical parameters is the Leaf Area Index (LAI).

LAI is the area of one leaf side per unit surface area [5]. Through this definition, LAI is a matter related to a form of the canopy in the ecosystem. LAI regulates microclimate conditions in the canopy, determines and controls the process of water absorption in the canopy, radiation barrier, and controls the exchange of water and carbon which is the biochemical cycle in the ecosystem [6]. Therefore, LAI is used as the basis for ecological, meteorological, and hydrological modelling. LAI can also be used as an indicator in knowing the level of health of mangrove [7] so that LAI has a function as a predictor in monitoring mangrove conditions related to pollution and climate change. LAI from mangrove vegetation depends on species composition, development stage, habitat conditions, seasonal conditions, and management practices. LAI is a dynamic parameter, where changes occur in the condition of LAI from time to time (spring and autumn) which controls the dynamics of the forest ecosystem [8]. The dynamics of LAI in the ecosystem are then combined with methods approved by LAI through the vegetation index. Concerning the important properties of a vegetation canopy (LAI), an appropriate method is needed in analysing LAI to understand the condition of mangroves.

The study of the relationship of SVI to LAI values is interesting to study in order to find out how the vegetation indices responds to the spectral characteristics of mangroves through LAI. [9] stated that the use of SVI as a proxy in conducting LAI modelling can be done. Broadly speaking, the approach taken to conduct LAI modelling is through a semi-empirical approach, namely the relationship between the SVIs and the LAI value obtained in the field is realized through correlation and regression analysis between the two variables. The value of LAI is obtained through hemispherical photos shoot. Hemisphere photography captures the pattern of light penetration in the canopy in a canopy structure so that the leaf area units can be quantified [5]. Hemisphere photography has advantages in distinguishing spatial aspects of an object, which are generally used to obtain leaf number distribution, and distance fraction (fraction gap) at different zenith and azimuth angles and can be combined with software [10]. Each vegetation index has a different spectral response to the value of LAI. The use of different vegetation indices will influence the correlation and regression values and the accuracy of LAI modelling so that the selection of vegetation indexes that have a strong relationship with LAI are needed. Previously [11] conducted a study to determine the relationship of SVI to the value of LAI. Eight vegetation indices were used in the study, namely Simple Ratio (SR), Normalized Differential Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Green Atmospherically Resistant Vegetation Index (GARI), Wide Dynamic Range Vegetation Index (WDRVI), Green Chlorophyll Index, Red-edge Chlorophyll Index, and MERIS Terrestrial Chlorophyll Index. The SVIs was used as a reference in a study conducted in Perancak Estuary, Bali using high spatial resolution images, namely WorldView-2 image recording date September 18, 2018.

The objectives of this study are to (1) compare and contrast the performance of several SVIs applied to WorldView-2 (WV-2) image to estimate the LAI, and (2) find the most accurate model for estimating LAI of mangrove forest in Perancak Estuary, Bali. Five SVIs are used that have strong relationships with LAI to achieve those goals, namely Simple Ratio (SR), Normalized Differentiated Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Green Atmospherically Resistant Vegetation Index (GARI), Wide Dynamic Range Vegetation Index (WDRVI).
2. Materials and Method

2.1. Study Sites
Perancak Estuary is centered at 232850 E and 9072050 N (UTM zone 50M) and part of the administrative area of Jembrana Regency, Bali Province, Indonesia. Perancak Estuary is dominated by land use in the form of ponds and mangrove vegetation. This estuary contributes to the diversity of various mangroves in which there are 9 types of mangrove species namely Sonneratia alba, Rhizophora apiculata, Avicennia marina, Bruguiera gymnorrhiza, Rhizophora stylosa, Rhizophora mucronata, Ceriops decandra, Ceriops tagal, and Excoecaria agallocha. Field measurements were carried out on July 9-17, 2018 with a total sample of 50 samples. The sample technique used is a transect based on mangrove density. The spectral pattern in the image was used as a reference in sampling. A total of 50 samples were collected in this study. Perancak mangrove conditions are dominated by species of Rhizophora sp and Avicennia Sp. The mangrove area in the Perancak is strongly influenced by the tides. There are differences in the highs and lows in every day. During the field work, the low tide conditions occurred in the morning at 8-12 am, and the high tide conditions occurred during the day from 13.00-17.00 p.m with varying height. The research location can be seen on Figure 1.

Figure 1. Map of (a) study area of Perancak Estuary, Bali and (b) sample distribution in Perancak Estuary, Bali (blue symbol is model samples and yellow symbol is validation sample; image composition used 743).
2.2. Field LAI Measurement

Field LAI was measured in the field using the hemisphere photography technique. This method utilizes a digital camera with a fish eye lens for photographing canopy density at the hemisphere height, which is more or less at an altitude of 1.5 m. The shooting technique can be seen in Figure 2. The shooting was carried out on each sample plot which the number of photos taken are nine photos. The plot used was 4 x 4 m. This sample plot is used as boundaries for measuring the value of mangrove LAI. The sample plot used in this study is adjusted to the WorldView-2 image resolution size and Circle of Interest (COI) of the hemisphere shooting parameters. The size of 4 x 4 m is considered to be in accordance with COI and can quantify the value of leaves effectively than using a 2 x 2 m sample plot size. The sample plot is made by stretching a rope to form a 4 x 4 m sample size. In the plot, Global Navigation Satellite System (GNSS) receiver was placed to record the position of each measured sample. The GNSS receiver was placed in the middle position of the plot then turned on, recorded, and copied to record the coordinates of the sample point. This activity was carried out on each sample plot in both sample models and validation samples. In addition, canopy shooting, tree height measurements and species identification were measured to support the analysis. The results of the hemisphere shoot are processed using CAN-EYE software to obtain the value of field LAI.

Figure 2. (a) Hemispherical photography technique, (b) Example result of hemispherical photograph

2.3. Spectral Vegetation Indices (SVI)

Values obtained for mangrove LAI each sample plot were used to compute the SVIs. Basically, the VIs is combination of red (R) and near-infrared (NIR) bands. SVIs are related to broadband greenness. In this case, mangrove vegetation is suitable to analysed by SVIs. Broadband greenness SVIs compare and make contrast spectral reflectance from the reflectance of mangrove LAI in the near-infrared range to another spectral reflectance in the red range, where chlorophyll absorbs the red wavelength photon into energy through photosynthesis. Use of near-infrared as a process of SVIs computation for LAI is effective, because near-infrared have much greater penetration depth through the canopy than red. But pixels composition mangrove is little complex. Mangrove has a spectral reflectance by water objects, soil, and vegetation which affect the spectral reflection characteristics of mangrove vegetation. So other formulation of SVIs need to applicate using other band like Green and Blue bands that sensitive to water and soil object. Because the LAI features are spectrally related to SVIs, many of the SVIs can work effectively, even with image data collected from broadband multispectral sensors, such as WorldView-2. Applications include vegetation phenology like LAI modelling can be implemented with remote sensing technology using SVIs analysis [12]. The main characteristics of the SVIs chosen for this study are listed in Table 1.
The \(\alpha\) is weighting coefficient of WDRVI. In this study \(\alpha = 0.2\) according to [13]. The \(\gamma\) is another weighting coefficient of GARI with value \(\gamma = 0.25\) according to [14]. NIR: near-infrared, R: red, B: blue.

### Table 1. List of vegetation indices used in this study including acronym and formulation

| Index                          | Formulation                                                                 | Reference                  |
|--------------------------------|-----------------------------------------------------------------------------|----------------------------|
| SR-Simple Ratio                | \((\text{NIR}/\text{R})\)                                                  | Jordan, 1969               |
| NDVI-Normalized difference vegetation index | \((\text{NIR-R})/(\text{NIR+R})\)                                         | Rouse et al., 1974         |
| EVI-Enhanced vegetation index  | \(2.5\times((\text{NIR}/\text{R})/((\text{NIR}+\text{R})+(6\times\text{R}-(7\times\text{B}))+1))\) | Huete et al., 1996        |
| GARI-Green atmospherically resistant vegetation index | \(\frac{\text{NIR} - [\text{Green} - \gamma(\text{Blue} - \text{Red})]}{\text{NIR} + [\text{Green} - (\text{Blue} - \rho\text{Red})]}\) | Gitelson et al., 1996     |
| WDRVI-Wide dynamic range vegetation index | \(\frac{\alpha(\text{NIR} - \text{Red})}{\alpha(\text{NIR} + \text{Red})}\) | Gitelson et al., 2004     |

The \(\alpha\) is weighting coefficient of WDRVI. In this study \(\alpha = 0.2\) according to [13]. The \(\gamma\) is another weighting coefficient of GARI with value \(\gamma = 0.25\) according to [14]. NIR: near-infrared, R: red, B: blue.

### 2.4. LAI Data Processing

LAI data processing is using CAN-EYE Software. This software quantifies photos of hemisphere shots. The nine photos that have been photographed in each sample are the main data in the quantification process which can then be referred to as the Elementary Sampling Unit (ESU). Before doing the data process, the camera calibration is done to determine the camera's focus point, namely the optical center process and projection function calibration. After calibrating, defining parameters needs to be done. This is the pre-processing stage. Parameters that need to be filled which are username, image size, optical center & projection function, Circle of interest (COI), Sub-sample factor, angular resolution, Cover, and FAPAR. The processing phase consists of the process of selecting photos to be processed. The correction stage called gamma correction is done to adjust the saturation and masking process is optional process when there are objects that cover the photo such as large rods or users. The final process of processing is photo classification. The class chosen is two classes. They are green vegetation and sky as background. These classes have a meaning that there are only two classes that will be classified, namely green vegetation and sky. This classification is optimal for quantifying leaves and canopies. The results of the classification are LAI data in the form of excel and graphics.

### 2.5. Computation of spectral vegetation indices (SVI) that related to LAI field values

In this study five vegetation indices were used which had a strong relationship with the value of mangrove LAI. They are Simple Ratio, SR [15], Normalized Difference Vegetation Index, NDVI [16], Enhanced Vegetation Index, EVI [17], Green Atmospherically Resistant Vegetation Index, GARI [14], and Wide Dynamic Range Vegetation Index, WDRVI [13]. The five vegetation indices have a characteristic to capture the spectral reflectance of LAI mangroves. SR is a simple index where the contrast of the NIR and R channels in reflecting spectral values of vegetation can produce a strong relationship with the value of mangrove LAI. NDVI can measure the health level of green vegetation associated with LAI. The disadvantage is the saturation of NDVI when associated with dense vegetation. EVI is built from Moderate Resolution Imaging Spectroradiometer (MODIS) image data which has advantages in increasing sensitivity to LAI. GARI is sensitive to chlorophyll concentrations and can reduce atmospheric effects better than NDVI. WDRVI similar to NDVI, but the weighting factor (\(\alpha\)) is
used to reduce the saturation of NDVI. This index is sensitive to high vegetation density. In NDVI when the density and LAI values increase, the index will be constant while WDRVI can reach a wider range. This index is effective when the NDVI index is saturated. Blue band are used to reduce soil reflections and atmospheric scattering. These five vegetation indices are used to determine the relationship of the value of each SVI with the value of mangrove LAI in the field.

SR, NDVI, EVI, GARI, and WDRVI are calculated using spectral reflection values from several channels on WorldView-2 images on the September 18, 2018 recording date, namely (blue: 450-510 nm), (green: 510-580 nm), (red: 630-690 nm), and (NIR: 770-895 nm). WorldView-2 image selection is based on its ability to capturing the reflection of spectral vegetation, especially mangroves. The five indices were formulated to produce values, but before that the process of mangrove masking in the study area was done, so that the pixel values used to analyse LAI were only pixel and spectral values of mangroves. Masking is done by separating mangrove objects from other objects.

The LAI mangrove modelling in this study is using semi-empirical approach by connecting the spectral values of the vegetation indices as independent variables and the field LAI values obtained from the hemisphere photograph as the dependent variable. The analysis used is Pearson Product Moment correlation and simple linear regression analysis. The value of each vegetation indices and field LAI will be processed to produce a relationship graph which can be seen in Table 2.

| Sample Number | LAI Values | NDVI | SR | EVI | GARI | WDRVI |
|---------------|------------|------|----|-----|------|-------|
| 1             | 2.18       | 0.8186 | 10.0259 | 0.7269 | 0.3688 | 0.3345 |
| 2             | 1.27       | 0.7594 | 7.3123 | 0.501 | 0.2512 | 0.1878 |
| 3             | 0.43       | 0.6979 | 5.6211 | 0.4601 | 0.2425 | 0.0585 |
| 4             | 1.34       | 0.7859 | 8.3432 | 0.532 | 0.2636 | 0.2506 |
| 5             | 1.36       | 0.7863 | 8.3579 | 0.5936 | 0.2963 | 0.2514 |
| 6             | 0.96       | 0.7108 | 5.9152 | 0.4889 | 0.258 | 0.0839 |
| 7             | 1.24       | 0.7572 | 7.2369 | 0.5174 | 0.2592 | 0.2689 |
| 8             | 1.68       | 0.805 | 9.2582 | 0.6763 | 0.3403 | 0.1828 |
| 9             | 1.2        | 0.755 | 7.1639 | 0.4836 | 0.2444 | 0.1779 |
| 10            | 1.7        | 0.8054 | 9.2797 | 0.6216 | 0.3047 | 0.2997 |
| 11            | 1.2        | 0.7551 | 7.1672 | 0.4598 | 0.2334 | 0.1781 |
| 12            | 1.98       | 0.8155 | 9.8408 | 0.5759 | 0.2798 | 0.3262 |
| 13            | 1.93       | 0.8144 | 9.7773 | 0.5871 | 0.2835 | 0.3233 |
| 14            | 1.32       | 0.7801 | 8.0931 | 0.5815 | 0.2895 | 0.2362 |
| 15            | 1.67       | 0.8002 | 9.0083 | 0.5651 | 0.2754 | 0.2861 |
| 16            | 1.16       | 0.7374 | 6.6166 | 0.4584 | 0.2356 | 0.1392 |
| 17            | 2.37       | 0.8273 | 10.5809 | 0.6769 | 0.3291 | 0.3582 |
| 18            | 1.77       | 0.8104 | 9.5507 | 0.5656 | 0.2744 | 0.3128 |
| 19            | 1.29       | 0.7743 | 7.86 | 0.5735 | 0.2859 | 0.2224 |
| 20            | 1.04       | 0.7163 | 5.8129 | 0.3595 | 0.2034 | 0.091 |
| 21            | 0.68       | 0.7064 | 6.9723 | 0.3895 | 0.2116 | 0.0752 |
| 22            | 1.41       | 0.7894 | 8.4964 | 0.5661 | 0.2797 | 0.2591 |
| 23            | 1.23       | 0.7916 | 8.5945 | 0.6263 | 0.313 | 0.2644 |
| 24            | 1.69       | 0.805 | 11.1932 | 0.7481 | 0.364 | 0.3825 |
| 25            | 1.57       | 0.7961 | 8.8091 | 0.5977 | 0.2946 | 0.2758 |
The model validation was done using the Root Mean Squared Error (RMSE) method and Standard Error Estimate (SEE). The sample used as a validation sample for the model amounted to 16 samples from 50 samples that obtained in field measurements from 9-17 July 2018 in Perancak Estuary, Bali. Previously, the Kolmogorov-Smirnov normality test was carried out where the model data and validation were normally distributed. The overall research procedure in this study is illustrated in Figure 3.
3. Results and Discussion

3.1. SVIs comparison
Table 3 shows a simple linear regression function with the value $R^2$ for each relationship between all vegetation indices and the value of mangrove LAI. In each relationship also produced the root mean squared error (RMSE) from the prediction of LAI through SVIs. Figure 5a, b, c, d, e shows a linear regression plot between SVIs and mangrove LAI values.
Correlation analysis between the values of SVIs are SR, NDVI, EVI, GARI, and WDRVI with the value of LAI mangroves shows a strong relationship. The RMSE of the five vegetation indices is also low and has high accuracy. The SR, NDVI, and WDRVI indices have a very strong relationship with the highest determination coefficient, $R^2 = 0.83$ with RMSE of 0.18 while the $R^2$ values of SR and WDRVI are 0.81 and 0.77 with RMSE of 0.22 and 0.25. The relationship between EVI and WDRVI and value of LAI is quite strong, that is equal to 0.53 and 0.44 which can be seen in Table 3. There are several factors that cause these results, one of the reason is that SVI with ratio index has more value strong relationships such as research [18] which explain that the SR, NDVI, and WDRVI have good ability to estimate the value of LAI. The contrast between the near-infrared and the red channel is very sensitive to the value of vegetation reflection mainly related to LAI. WDRVI almost has the same formulation with NDVI but the difference is the weighting coefficient in WDRVI which is used to solve the saturation problems in NDVI. But in this study, NDVI looks not saturated because NDVI still has a strong relationship to value of LAI than WDRVI. The EVI index that uses blue channels is enough to produce $R^2$ which is classified as quite strong relationship but not stronger than the three indices described (SR, NDVI, and WDRVI). The blue channel in the EVI formulation is used to reduce the atmospheric scattering, but WorldView-2 imagery is used in this study has only a small amount of atmospheric interference, so this affects the correlation result between EVI values and mangrove LAI values from field measurements. The GARI index is classified as a moderate correlation level because this index is more sensitive to chlorophyll than LAI.

### 3.2. LAI Modelling using Regression Analysis

LAI modelling in this research is built through simple linear regression analysis. The simple linear regression equation used is in the form of equations (1)

$$ y = ax + b $$  \hspace{1cm} (I)

The independent variable in this regression analysis is the SVIs value as a proxy while the dependent variable is the value of the LAI from field measurements result. The value of the regression function of each index on the value of LAI can be seen in Table 2. The relationship of the regression plot graph can be seen in Figure 4. Through the regression plot graph, it can be explained that all SVIs have sufficient ability to estimate mangrove LAI but NDVI has more unique characteristics that has a strong correlation with the value of LAI.
relationship to the value of LAI. Because of that, NDVI is the most relatable SVI to be applied to the WorldView-2 image in estimating the LAI model in Perancak Estuary, Bali with a high $R^2$ value and low RMSE.

Figure 4. Regression function plot between SVI and field LAI values: (a) NDVI and LAI, (b) SR and LAI, (c) EVI and LAI, (d) GARI and LAI, (e) WDRVI and LAI.

3.3. SVI Accuracy to LAI Model
The validation of the LAI model built was applied with the Standard Error Estimate (SEE). Previously the validation samples that used to validate the model were normally distributed after the normality test by the Kolmogorov Smirnov test. The mean and StDev generated can represent the model that has been built. The SEE calculation results can be seen in Table 4 which shows that NDVI has the highest accuracy compared to other vegetation indices, which is 89.10%. A little better than the accuracy of SR and WDRVI, which are 87.10% and 85.34%. This can be explained that NDVI through the 89.10% accuracy value has the ability to estimate LAI and the best index in mangrove LAI modelling in Perancak Estuary, Bali.
Table 4. LAI model accuracy assessment using Standard Error Estimate (SEE) calculation

| SVI   | Mean | StDev | Max Error | Min Error | Max Accuracy | Min Accuracy |
|-------|------|-------|-----------|-----------|--------------|--------------|
| SR    | 1.51 | 0.39  | 14.7      | 12.91     | 87.08        | 83.3         |
| NDVI  | 1.45 | 0.39  | 14.28     | 10.89     | 89.10        | 85.72        |
| EVI   | 1.50 | 0.29  | 23.46     | 19.34     | 80.65        | 76.53        |
| GARI  | 1.49 | 0.25  | 24.75     | 20.90     | 79.09        | 75.24        |
| WDRVI | 1.52 | 0.36  | 18.58     | 14.65     | 85.34        | 81.41        |

4. Conclusion
The five vegetation indices that are SR, NDVI, EVI, GARI, and WDRVI has a relationship with the value of mangrove LAI from the field measurements result with $R^2$ values above 0.4 where the correlation is classified as strong level but only the SR, NDVI, and WDRVI indices are strongly correlated with LAI value. All three indices have $R^2$ values above 0.7 with low RMSE. This indicates even though there are differences in the value of relationships on each index but SVIs can still be applied to the image of WorldView-2 to estimate mangrove LAI in Perancak Estuary, Bali. The model with the best accuracy is NDVI which has an $R^2$ value of 0.83 and an accuracy of 89.10%.

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