The effect of image radiometric correction on the accuracy of vegetation canopy density estimate using several Landsat-8 OLI’s vegetation indices: A case study of Wonosari area, Indonesia

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Abstract. Recent studies on the use of spectral indices have involved radiometric correction as a prerequisite. However, study on the effect of radiometric correction level on the accuracy of biophysical parameters’ estimate is still rare in Indonesia. This study tried to investigate the influence of various radiometric correction levels and the number of vegetation strata on the accuracy of vegetation density estimates using NDVI, MSAVI2 and GEMI of Landsat 8 OLI. In this study, the dataset covering vegetated area in Wonosari, Gunung Kidul Regency, Indonesia was processed radiometrically using eight different methods, i.e. spectral radiance, at sensor reflectance, sun elevation correction, histogram adjustments using original DN, spectral radiance, at sensor reflectance, and sun position correction respectively, as well as dark object subtraction (DOS). Every image with specific correction level was then transformed using the aforementioned indices, in order correlate with the field-measured canopy density. The analysis were carried out by considering the number of canopy layers. This found that different radiometric correction methods resulted canopy density estimates with different accuracies. The number of canopy strata also played an important role. Every vegetation index transformation performed its best accuracy by using different radiometric correction method and different number of canopy layers.

1. Introduction
Vegetation mapping is one of the most prominent applications of remote sensing. When a quantitative assessment of biophysical parameters of vegetation is required, vegetation index transformation is a common approach to this activity [1]. On the other hand, many studies also showed that the use of spectral transformations might lead to different results when the spectral bands are neither calibrated nor radiometrically corrected [2-4]. Therefore, several authors also accentuated the importance of radiometric corrections in vegetation spectral analyses [5-7]. Accuracy of vegetation biophysical parameters’ estimates have been studied by several authors [8][4]. Although the vegetation indices generally require radiometric preprocessing, there were only limited number of papers explicitly reported that those treatment had been carried out.

Many authors also claimed that there are several factors related to biophysical parameters of vegetation causing variations in their spectral responses, e.g. vegetation types/species, soil background, number of canopy layers or strata [8-9,1]. During the past 20 years, many researchers processed multispectral image up to at-surface reflectance as the input to the vegetation index transformation, assuming that the parameter is the best measurable factor to represent the biophysical phenomena.
Based on the aforementioned background, it is important to assess the influence of radiometric correction and calibration on the vegetation canopy density estimate. Therefore, the objectives of this study were twofold, i.e. (a) to assess the importance of radiometric correction/calibration on the use of three vegetation indices (NDVI, MSAVI2, and GEMI) for estimating vegetation density in relatively flat area, (b) to evaluate the effect of radiometric correction/calibration on the accuracy of vegetation index-based canopy density estimate by considering the number of strata.

2. Previous Works

Vegetation index is a group of image transformation that uses of two or more vegetation-sensitive bands to generate new images that are more representative to show density-related variation. [3] explained that there are two groups of vegetation index, i.e. generic (e.g. SR, NDVI) and empirical ones. The empirical vegetation indices can be grouped into (a) the ones that can suppress the soil background influence (e.g. SAVI, TSAVI, MSAVI, MSAVI2), and (b) the ones than can suppress the atmospheric effects (e.g. ARVI and GEMI). Studies carried out by [11] showed that many applications in Indonesia simply used a vegetation index formula without a deep consideration on its development background.

In terms of vegetation composition [12], and [13] explained that vegetation can be described with respect to either its floristic or species composition or its structural composition. Any species may differ from others as viewed from its spectral response in particular range of wavelengths [10]. On the other hand, different vegetation structural compositions also give significant difference in spectral responses, since different canopy geometry and number of leaves’ layer absorb, reflect and transmit electromagnetic radiation differently [14]. In short, the number of canopy layer (strata) plays an important role in absorbing and reflecting the EMR, particularly when near infrared spectrum is involved.

Discussed the effect of radiometric correction on SPOT HRV and Landsat TM NDVI data [2]. Their results show that: (a) the conversion of DN into apparent reflectance is the most important step for NDVI correction. Without this correction, a relatively constant error affects NDVI depending on the sensor considered; (b) MTF correction did not affect the average NDVI value; its interest is to restore the radiometric level of individual pixels that have a large contrast with their surroundings; and (c) the atmospheric effects were similar in the homologous spectral bands of SPOT-HRV and Landsat TM. Their correction increased the dynamic range of NDVI variation (around 24% in the example presented) and consequently the contrast between different targets.

The effect of radiometric corrections on carbon stock estimate using vegetation index approach [5]. However, their study only took into account four correction levels, i.e. histogram adjustment, shadow calibration, at-sensor reflectance, and at-surface reflectance. The study was carried out in urbanised area with heterogeneous terrain, and it mostly covered heterogeneous vegetation. Six vegetation indices were involved, i.e. EVI2, NDVI, TVI, ARVI, SAVI, MSARVI. They found that the at-sensor and at-surface reflectance calibrations were the most effective and stable corrections for estimating biomass and carbon stock at the study area. In addition, MSARVI was the most accurate vegetation index based on the at-sensor and at-surface reflectance images. The study did not include MSAVI2 and GEMI.

3. Study Objectives

This study tried to investigate the influence of various radiometric correction methods/levels and the number of vegetation strata on the accuracy of vegetation density estimates using NDVI, MSAVI2 and GEMI of Landsat 8 OLI. In this study, the dataset covering vegetated area in Wonosari, Gunung Kidul Regency, Indonesia was processed radiometrically using eight different methods, i.e. spectral radiance, at sensor reflectance, sun elevation correction, histogram adjustments using original DN, spectral radiance, at sensor reflectance, and sun position correction respectively, as well as dark object subtraction (DOS).
4. Materials and Methods

4.1 Materials and method
This study made use of Landsat-8 OLI image covering Wonosari area, Gunung Kidul Regency (path 120 row 065, see Figure 1). The image was recorded on 24 June 2013. Preprocessing stages comprised geometric and radiometric corrections. The geometric correction referred to RBI topographic map at scale of 1:25,000 using third order transformation, since the coverage is mountainous in some parts and flat until rolling in other parts—although the study area is situated in relatively flat up to gently sloping.

![Study area](image)

**Figure 1. Study area**

4.1.1. Radiometric corrections
The radiometric correction comprised eight different types or level of corrections, including (a) calibration from DN to spectral radiance, (b) calibration from DN to histogram, (b) adjustment of original DN to reflectance, (c) sun position adjustment, (d) histogram adjustment of original DN, (e) histogram adjustment of the spectral radiance, (f) histogram, adjustment of the reflectance, (g) histogram adjustment of the sun position, and (h) dark object subtraction of the reflectance. Topographic correction was not carried out since the study area is relatively flat or at least the topographic variation is minimum.

The spectral radiance $L\lambda$ is defined as $L\lambda = MLQcal + AL$, where $L\lambda = TOA$ spectral radiance (Watts/(m$^2$ * sr * $\mu$m)), $ML =$ Band-specific multiplicative rescaling factor from the image header (Radiance Multiplicative Band$_x$, where $x$ is the band number to be corrected), $AL =$ Band-specific additive rescaling factor from the image header (Radiance Additive Band$_x$, where $x$ is the band number to be corrected), $Qcal =$ Digital Number of the band to be corrected.

The top of atmosphere planetary (TOA) reflectance $\rho\lambda'$ is defined as $\rho\lambda' = MPQcal + AP$, where $\rho\lambda' =$ TOA planetary reflectance, without sun angle correction, $MP =$ Band-specific multiplicative rescaling factor from the image header (Reflectance Multiplicative Band$_x$, where $x$ is band number to be corrected), $AP =$ Band-specific additive rescaling factor from the image (Reflectance Additive Band$_x$, where $x$ is band number to be corrected), and $Qcal =$ Digital Number (DN).

The sun position correction generate $\rho\lambda$, where $\rho\lambda = \rho\lambda'\cos(\thetaSZ) = \rho\lambda'/\sin(\thetaSE)$, where $\rho\lambda' =$ TOA planetary reflectance, without sun angle correction, $\thetaSZ =$ local sun elevation angle. The scene center sun elevation angle in degrees is provided in the metadata (SUN_ELEVATION), and $\thetaSZ =$ Local solar zenith angle; $\thetaSZ = 90^\circ - \thetaSE$. 
The dark object subtraction method produced corrected image with new value $R_c = R_s - R_{si}$, where $R_c =$ Object reflectance value which is atmospherically corrected, $R_s =$ Object reflectance value before correction, $R_{si} = (\text{Mean } R_{w} - (2*\text{Standard Deviation } R_{w}))$, and $R_w =$ spectral value which is considered as an offset.

In the next stage, all datasets with different level of processing were then transformed using three different vegetation indices, i.e. NDVI, MSAVI2, and GEMI, resulting 24 different images containing vegetation index information. The indices involve brightness values (BV) in various expressions, including the original digital number (DN), spectral radiance, and reflectance. The formula for NDVI is $NDVI = (BVI_R - BV_{IR})/(BVI_R + BV_{IR})$, where R and IR are red and near-infrared bands respectively. The formula for MSAVI2 is $MSAVI2 = (0.5)*((2*(BV_{IR}+1))-(\sqrt(((2*BVI_R)^2)-(8*(BV_{IR}-BV_R)))))$, while the formula for GEMI is $GEMI = \eta \times (1-(0.25*\eta)) - ((BV_R - 0.125)/(1-BV_{IR}))$, where $\eta = ((2(BV_{IR2} - BV_{R2})+(1.5*BV_{IR2})+(0.5*BV_{R2}))/((BV_{IR2}+BV_{R2}+0.5))$.

4.1.2. Field Measurement and Data Analysis

Vegetation canopy density measurement was carried out one year after, at the same date. The field data was grouped into two separate subsets, i.e. field data for developing regression model, and field data for accuracy assessment. Measurement of canopy density was undertaken using circular fish eye camera (5.6 mm focal length) at 30x30 m², and by taking into account the number of strata (layer), ranging from one up to four, and combinations between them, e.g. two and three strata, two, three and four strata. Analysis of canopy density was done using image processing software to measure the vegetation percentage.

Statistical analysis was carried out to correlate the canopy density and the vegetation index value of each image, at various strata. Based on this analysis, the best radiometric correction in relation with the best vegetation index for estimating the canopy density could be found. Moreover, advantages and disadvantages of each correction and index could also be discussed.

5. Results and Discussion

5.1. Radiometric Corrections

An RMS error of 0.56 was obtained using a third order transformation, indicating that the image is suitable enough for field orientation, vegetation canopy density measurement and mapping. In this geometric correction, a nearest neighbor interpolation was chosen, instead of bilinear or cubic convolution resampling, in order to maintain the original pixel values. The original DNs range from 0 to 65,535 (16 bit coding), and they were calibrated/corrected using eight different methods as shown in Figure 1, which depict spectral pattern of vegetation in the study area.

![Figure 2](image-url) The graphical results of radiometric corrections (B up to I) as compared to original DN (A).
The figures show that only some of the radiometric correction methods (E – I) could derive spectral patterns similar to theoretical or ideal vegetation spectral curve [14]. It is understandable since the corrections/calibrations in Figure 2 B-D only either shifted the DN to 0 or converted the original DN to spectral radiances. The corrections shown in E-I combined them, which means that they also reduced the atmospheric effects. The most affected bands in these stages were visible ones. The Dark Object Subtraction method could also reduced the intensity of SWIR1 band values so that they dropped into much lower values than those of NIR band.

5.2. Vegetation Canopy Density Measurement
Vegetation types and maturity in the study area varied. The variation was related to the number of strata. Teak (*Tectona grandis*) and understory vegetation such as shrub and herb dominated two strata category. Vegetation with three strata was dominated by herbes and a mixture between teak stands and cashcrops (palawija), including ground nuts, cassava and sweet potato. Vegetation with four strata was dominated by various types of trees, shrub, and herbs. Vegetation with one or five strata was also found, but in general they only occupied areas smaller than the minimum area of observation (less than 64x64 m²).

Vegetation canopy measurement was carried out by taking into account the pixel size and RMS error. The width of the sample’s rectangle A is defined as $A = P(1+2*RMSe)$, where P is the spatial resolution (30 m), while RMSe is 0.56 according to the geometric correction results. Area of 64x64 m² size for each sample was then set to represent the canopy density of the homogeneous pixels.

In each area sample, nine points were used as the basis for making circular fisheye photographs of the canopy. The photos were taken upward from the ground. The averaged value of every nine photos was used to represent the canopy density. This study separated samples into two groups, i.e. the one for building up regression model and the other one for accuracy assessment. The measured canopy densities were then correlated with the vegetation indices.

5.3. Correlation between the canopy density and the vegetation indices
Correlation and regression analyses of the canopy density and vegetation index for different radiometric correction methods and different number of strata were carried out, resulting 96 variations of correlation coefficients and regression equations, which were then compared and evaluated. It is interesting to note that the simplest radiometric correction, i.e. histogram adjustment of the original DN did not perform badly, except for the GEMI vegetation index. The use of NDVI and MSAVI 2 of the corrected image gave a relatively high correlation coefficient, at the same values, i.e. 0.817 for four strata. Correlation between the corrected image and the canopy density at three strata gave slightly lower $r$, i.e. 0.792 and 0.799 respectively. With the GEMI, the correlation coefficients between canopy density and the vegetation index for various canopy strata were too low to be proceeded to regression-based estimation model.

For the NDVI, the most consistent radiometric correction method in terms of correlation coefficients with the canopy density (for various numbers of strata) was the dark object subtraction. The dark object subtraction method performed good $r$ for all number of strata, with the lowest value of 0.81. The lowest correlation coefficient with the canopy density was obtained using at-sensor reflectance method, which showed relatively inconsistent $r$ values for different strata. The MSAVI2 showed inconsistent $r$ values when the histogram adjustment of at-sensor reflectance and dark subtract correction methods were used. Although the $r$ values were relatively high, the discrepancy between them was also wide. A better performance in terms of high and consistent $r$ values was found with the at-sensor radiance correction method. When the correlation coefficients of all combination have been found high enough, and they were statistically significant, this study continued with the regression-based equations to estimate the canopy density. Several results obtained using GEMI with different radiometric correction methods were not used due to their insignificant correlation coefficients.
5.4. Estimated Canopy Density Accuracies

This study found that different radiometric correction methods generated canopy density models with different accuracy levels. Besides the radiometric corrections, variation in the number of strata also played an important role. Generally speaking, there was no single radiometric correction that can be used as the best method for all numbers of canopy strata and all vegetation indices involved.

When the regression models were used to estimate the canopy density of the study area using NDVI, this simplest correction method also showed a higher accuracy level than other correction methods except dark subtract. When the MSAVI2 was used, the accuracy level achieved for four strata was still higher than the majority of radiometric corrections, except at-sensor radiance, at-sensor reflectance, and histogram adjustment of the TOA. Table 1 also shows that with NDVI, different radiometric corrections methods gave different canopy density estimate accuracies, when the number of strata was taken into account. MSAVI2 had the same tendency. On the other hand, GEMI only worked well for estimating the canopy density when the correction methods were applied using at-sensor reflectance, sun position, and histogram adjustment of those two resultants.

![Figure 3. Example of the canopy density estimation map using GEMI with histogram adjustment of sun-position correction method.](image)

| Table 1. Summary of the result |
|--------------------------------|
| **Correction method** | **Vegetation Index** | **Accuracy of vegetation canopy density estimate using original DN or corrected images:** |
| | | **At-Sensor Radiance** | **At-Sensor Reflectance** | **Sun Position correction** | **Histogram adjustment of original DN** | **Histogram adjustment of At-Sensor Radiance** | **Histogram adjustment of At-Sensor Reflectance** | **Histogram adjustment of Sun Position** | **Dark Object Subtraction** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| NDVI | High, for 4 strata | High for 3 strata and combined 2, 3 and 4 strata | High for 4 strata | High for 3 strata and combined 3 and 4 strata | High for 2 strata | High for 2 strata | High for 2 strata | High for 2 strata and combined 2 and 3 strata |
| MSAVI2 | High for 3 strata, combined 2 and 3, combined 3 and 4, and combined 2, 3 and 4 strata | High for 4 strata | High for 3 strata and combined 3 and 4 strata | High for 2 strata and combined 2 and 3 strata | High for 2 strata | High for 2 strata | High for 4 strata | High for 4 strata and combined 2 and 3 strata |
| GEMI | X Correlation coefficient is too low | X High correlation coefficient, but inverted | High for combined 3 and 4 strata | High for 3 strata, combined 2 and 3, and combined 3, 3 and 4 strata | X High correlation coefficient, but inverted | X High correlation coefficient, but inverted | X High correlation coefficient, but inverted | High for all variations of the number of strata |

* Categorized as ‘high’ if the accuracy is the highest in comparison with the other strata variation under the same variable.
6. Conclusions
This study concluded that radiometric corrections could increase the accuracy of vegetation canopy density maps, which were generated from Landsat-8 OLI using vegetation indices, in comparison with the original image. Different radiometric correction methods with different vegetation index formulas delivered different accuracy levels. The best canopy density map estimation accuracy was achieved using NDVI image that has been radiometrically corrected using Dark Object Subtraction, or using MSAVI2 with the at-sensor radiance image, or using GEMI with the sun position correction image. If the image data does not have any non-image information (i.e. image header) for the basis of radiometric correction, the original DN could still be used to deliver relatively accurate estimates for all number of strata, particularly using DNVI and MSAVI2. The number of strata gave significant effect on the accuracy of vegetation canopy density. By using NDVI, MSAVI2 or GEMI, it showed that the higher the number of strata, the higher the accuracy.

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