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The Effect of Topographic Correction on Canopy Density Mapping Using Satellite Imagery in Mountainous Area

Deha Agus Umarhadi[a,b], Projo Danoedoro[a,*]

[a] *Remote Sensing Laboratory, Department of Geographic Information Science, Faculty of Geography, Universitas Gadjah Mada, Yogyakarta, 55281, Indonesia*
E-mail: [*]projo.danoedoro@geo.ugm.ac.id

[b] *Graduate School of Environmental Science, Faculty of Environmental Earth Science, Hokkaido University, Sapporo, 060-0808, Japan*

***Abstract*— One of the main factors contributing to radiometric distortion on remote sensing data is a topographic effect, but it can be reduced by applying the topographic correction. This study identifies the effect of topographic correction on canopy density mapping in the Menoreh Mountains, Indonesia. Topographic correction methods examined in this research are C-Correction, Minnaert, and Sun-Canopy-Sensor+C (SCS+C). Canopy density estimation was approached using vegetation indices, i.e., Normalized Difference Vegetation Index (NDVI), Modified Soil Adjusted Vegetation Index (MSAVI), Aerosol Free Vegetation Index (AFRI) 1.6, and AFRI 2.1 derived from Landsat-8 OLI imagery. We evaluated the performance of topographic correction by visual and statistical analysis before comparing the accuracy of canopy density estimation of different vegetation indices and correction methods. The results showed that topographic normalization could increase the accuracy of canopy density mapping. The most significant improvement is the model using MSAVI, which increases by 1.207% using the Minnaert method to reach 86.692% accuracy. Meanwhile, NDVI, AFRI 1.6, and AFRI 2.1 have less significant improvement with the maximum increase of 0.241%, 0.057%, and 0.032% using the SCS+C method, reaching the accuracy of 88.980%, 83.303%, and 82.308%, respectively. The accuracies were slightly improved since the algorithms have already reduced the effect of topography, which are categorized as ratio vegetation indices. SCS+C is the best topographic correction method because of not only the appropriate assumption of canopy normalization but also its consistency and better accuracy in canopy density estimation, among other methods.**

***Keywords*— topographic correction; canopy density; Landsat-8; vegetation index.**

I. INTRODUCTION

Pre-processing in remote sensing analysis is essential before information extraction to reduce the errors. Several variables causing radiometric errors are atmosphere, terrain elevation, slope, and aspect [1]. Aspect and slope of the topographic condition influence the difference of sun illumination towards the ground. Slopes facing the sun directly produce higher value; on the other hand, the slopes facing away the sun have a lower value because the slopes cover the sun rays. The topographic condition leads to the effect of different solar light energy towards the earth's surface, and then it is captured by a satellite sensor based on the reflectance value from the earth's surface. The different energy captured by satellite data on the same objects would present different pixel values, and it affects the accuracy of information derived from that data. Hence, before the images are processed digitally, it needs pre-processing named radiometric correction, which includes topographic correction.

Topographic correction is categorized as radiation and atmospheric correction, which is needed to obtain the surface reflectance accurately [2]. This method corrects slope and aspect effects that can cause radiometric distortion on the image [1]. Topographic correction is essential to reduce the effect of hilly and mountainous terrain. Several research and studies about topographic correction have been widely conducted. The results showed topographic condition has an effect on reflectance value. Nevertheless, the effect can be repaired, or at least it can be reduced by applying the topographic correction. From those studies, various methods have been developed.

Topographic correction can be applied to the wavy and mountainous conditions and on all land cover types. Several researchers examined the topographic correction and focused on the method comparison in purpose to reduce topographic effects [3–8]. Most of them applied topographic correction on land cover classification [9] and forest mapping [10], whether it was multitemporal analysis or not. It was reported that the studies about increasing the accuracy of a continuous variable such as canopy density of vegetation by applying topographic correction were rarely conducted [11].

A multispectral classification, which is widely examined the effect of topographic correction, is based on band combination; meanwhile, canopy density estimation is approached by vegetation index. On the other hand, several vegetation indices can reduce several disturbances, including slope and aspect effects indirectly [12]. Adhikari et al. examined the effect of C-Correction on fractional tree cover and found that ratio-based vegetation indices were not affected significantly [11]. Leaf Area Index model using Minnaert topographic correction has succeeded in improving the result, but this previous research did not compare the result to the uncorrected image [13]. Information regarding canopy density is important since the quality of vegetation stands can be figured out from this information; regardless, there is no change to the extent [14], [15]. Moreover, this data is related to the carbon stock of vegetation [16].

Menoreh Mountains located in the Special Region of Yogyakarta and Central Java Province, was selected in this research. Previous research estimated vegetation cover in the part of this area resulted in vegetation density without paying attention to topographic effect [17]. As a result, the canopy density values are greatly affected by the slope and aspect condition. This study aims to identify the effect of several topographic correction methods applied in the canopy density estimation mapping using vegetation indices, which are derived from remote sensing imagery to find out the importance of this pre-processing method conducted.

II. Materials and Method

A. Satellite Imagery

Landsat-8 OLI imagery acquired on 22 February 2015 was used in this study due to its cloud-free condition among the other date images, which contain the atmospheric disturbance. Landsat-8 OLI is multispectral imagery that consists of 9 multispectral bands and a panchromatic band. The multispectral bands have 30 m spatial resolution and 16 days revisit time. We did not include band 1 (coastal aerosol). Band 9 (cirrus) was used to apply cirrus correction; hence this study used 7 bands (band 2-7 and 9) to examine the topographic correction. Landsat-8 imageries are freely accessed from http://earthexplorer.usgs.gov. Landsat-8 has been widely used and is reliable for vegetation studies on a medium scale. Although its level is on the geometrically corrected level, we conducted geometric correction based on the local topographic map.

Shuttle Radar Topography Mission (SRTM) 1 arc-second was used as a Digital Elevation Model (DEM) [9]. Since the topographic condition depicted on the Landsat image is the surface elevation, the use of the Digital Surface Model (DSM) from SRTM is more appropriate than the terrain model [18]. SRTM DEM provides widely digital elevation data covering 60º Northern to 56º Southern Latitude acquired on 11-22 February 2000. The spatial resolution of this level is the same as 30 m of Landsat-8 pixel size.

B. Canopy Density Measurement

Unmanned Aerial Vehicle (UAV) with a small format camera was used to measure canopy density downwardly. UAV method was chosen because this indirect measurement is easily conducted over the mountainous area, and it provides good results quite similar to the hemispherical photography method that has been widely used [19]. We equipped Color-Infrared (CIR) camera on DJI Phantom quad-copter. This camera is more sensitive to the vegetation aspect than the true-color camera. Several photo mosaics were made, and cropped in 45x45 m, with the center coordinate is the same as sample coordinate in Landsat-8 image. We considered using of 45x45 m grid to anticipate geometric shifting on the image. Aerial photographs processing used decision tree analysis to distinguish between the canopy and non-canopy object. We obtained a total of 93 canopy density data.

C. Atmospheric Correction

Surface reflectance was the result of calibration and atmospheric corrections of Landsat-8 image. We applied two atmospheric correction methods, i.e., cirrus correction and histogram adjustment correction. Calibration was purposed to convert a digital number (DN) of 1T level Landsat-8 to top-of-atmosphere (TOA) reflectance. Cirrus correction was applied firstly in the DN level using Cirrus Band as the subtraction parameter. After that, we converted the corrected DN cirrus to TOA reflectance. Histogram adjustment was conducted by subtracting the minimum value of TOA reflectance at each band to generate the reflectance value of the object.

D. Topographic Correction

Topographic correction is divided into two methods, i.e., band ratios and DEM-used correction [20]. We used the second one, hence SRTM DEM was required in this method to calculate the incident angle, which is the angle between normal angle and solar light [21]. The value of illumination, cosine of the incident angle, depends on the relative orientation of pixel towards sun position. Illumination ranges from -1 to 1, which is obtained from the equation:

$$\mathrm{IL} = \cos a \cos \theta_z + \sin a \sin \theta_z \cos(\phi_a - \phi_o) \quad (1)$$

where IL is the illumination; a is the slope angle; θ_z is the solar zenith angle; ϕ_a is the solar azimuth angle; and ϕ_o is the aspect angle [20]. We evaluated the effect of topographic correction on canopy density estimation using three methods: C-Correction, Minnaert, and Sun-Canopy-Sensor+C.

1) C-Correction: C-Correction is semi-empirical method that assumes the linear correlation between reflectance on each band and IL [20]. The equation of this semi-empirical is:

$$\rho_T = \mathrm{a} + \mathrm{b}\,\mathrm{IL} \quad (2)$$

where ρT is the surface reflectance each band; b is the slope of regression line each band, and a is the intercept of regression. C-Correction is defined with the equation:

$$\rho_H = \rho_T \left(\frac{\cos\theta_z + \mathrm{c}}{\mathrm{IL} + \mathrm{c}}\right) \quad (3)$$

where ρT is the corrected surface reflectance, this model introduced the c parameter as the quotient between slope (b) and intercept (a) of the regression equation, versus IL [20].

2) Minnaert: Non-Lambertian method is based on the ideas of Minnaert in 1941, who is the first person to propose a semi-empirical equation to assess the roughness of the moon's surface [20]. The equation of the Minnaert method is:

$$\rho_H = \rho_T \left(\frac{\cos\theta_z}{\mathrm{IL}}\right)^k \quad (4)$$

where k is the Minnaert that showed non-Lambertian behavior [21]. The value of k ranges between 0 and 1. K is obtained from the regression equation of linearization regression of previous semi-empirical method logarithmically that formulated as follows:

$$\log(\rho_T \cos a) = \log\rho_T + k\log(\cos a\ \mathrm{IL}) \quad (5)$$

3) Sun-Canopy-Sensor+C: Sun-Canopy-Sensor (SCS) method *removes* topographic effects by projecting the sloped surface to the horizontal surface with preserving the geometry of the canopy structure vertically [22]. The assumption used in this method is the geometry of terrain and trees is consistent. This term is different from C-Correction and Minnaert. Because the sun-canopy geometry is vertically upright, the SCS model is more appropriate than other methods. SCS model provides an overcorrection result. Hence Soenen et al. modified it by adding the C coefficient to become SCS+C [23]. The SCS+C method is expressed by:

$$\rho_H = \rho_T \left(\frac{\cos a \cos\theta_z + c}{\mathrm{IL} + c}\right) \quad (6)$$

E. Vegetation Indices

Vegetation indices based on multispectral data are more sensitive to vegetation phenomena than single bands can do. There are several vegetation indices, and each index has unique characteristics. Canopy density estimation using a vegetation index is widely used. This study used three vegetation indices, i.e., NDVI [24], MSAVI [25], and AFRI [26]. Landsat-8 has two shortwave-infrared bands, so AFRI has 2 indices, AFRI 1.6 and AFRI 2.1. The equations are formulated as follows:

NDVI = (ρNIR - ρRed) / (ρNIR + ρRed) (7)
MSAVI = ((ρNIR - ρRed) / (ρNIR + ρRed + L)) x (1+L) (8)
where L = 1 – (2s x NDVI x WDVI) (9)
AFRI 1.6 = (ρNIR – (0.66 x ρ1.6)) / (ρNIR + (0.66 x ρ1.6) (10)
AFRI 2.1 = (ρNIR – (0.5 x ρ2.1)) / (ρNIR + (0.5 x ρ2.1) (11)

III. Results and Discussion

A. Illumination

Illumination (IL) was generated according to equation (1). This equation required slope angle, aspect angle, solar zenith angle, and solar azimuth angle. Slope and aspect angle were generated from SRTM DEM, while solar zenith and solar azimuth angle were provided in Landsat-8 metadata. Although SRTM DEM is DSM, this data is suitable for the application of vegetation, because the height of objects can represent different slope and aspect. According to the metadata of Landsat-8, the solar zenith angle is 0.54393844232251 (radiance of 90°-SUN_ELEVATION), and the solar azimuth angle is 1.71274202295465 (radiance of SUN_AZIMUTH).

IL represents the cosine of the angle between the normal angle to the ground and the solar light. The value of IL represents the proportion of direct sun radiation to image pixels [27]. Visually, IL seems like hill-shading. It represents the actual sun exposure on 22 February 2015 at 09:47:56.1368875 Western Indonesian Time (GMT+7). SRTM DEM is global geometrically corrected, but it is required to be corrected to have the same geometric location as the Landsat-8 image. We conducted geometric correction on IL because it has better topography visualization than DEM. The study area is a complex mountainous area, as it is seen on IL value that ranges from 0 to 1 (see Figure 1). IL has the maximum value of 1 when the solar light is perfectly perpendicular to the ground, and it is decreasing as the angle is getting further from the normal line.

B. C and K Coefficient

C and K were obtained by applying empirical calculation between IL and surface reflectance of Landsat-8 image in the same land cover [28]. This study focused on the vegetation object. Hence we took samples of vegetation objects with the same characteristics. Samples were taken on various slope and aspect conditions. The number of 5,000 samples in this empirical method is recommended by Gao et al. [28], and we did so.

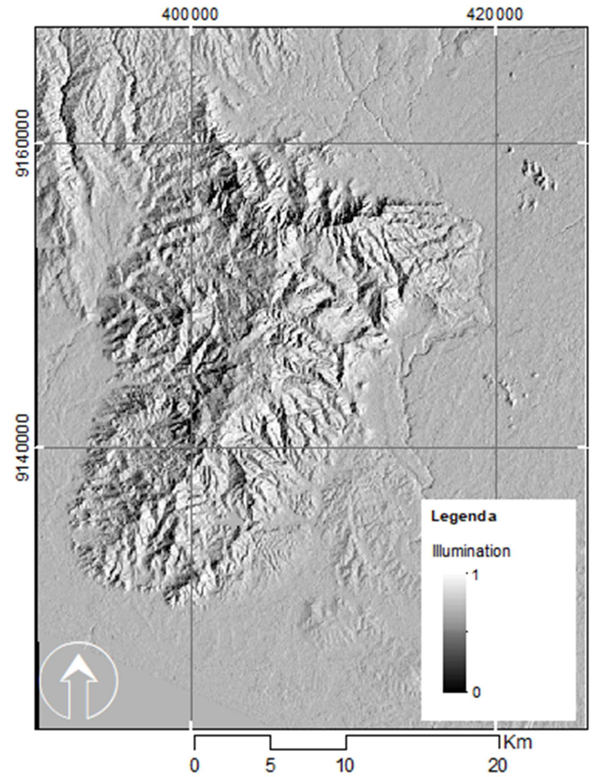


Fig. 1. Illumination (IL) image of the study area

The regression analysis put the IL as the independent variable (x-axis) and surface reflectance of each band as the dependent variable (y-axis). We involved all the Landsat-8 multispectral bands (2-7). As was mentioned before, the C coefficient was obtained from the quotient of the gradient and intercept of the regression line. Meanwhile, K was derived from the slope of the regression line by applying logarithmic linearization on each variable on the previous regression.

Table 1 shows the C and K coefficient on each band. C coefficient is the highest on the blue band (band 2), and it is getting lower as the length of the wavelength, and the lowest C is on the band 7. Conversely, the K coefficient has the highest value on band 7, and the lowest is on band 2. Mathematically, the C and K coefficient has the same effect in the correction [27]. C coefficient increases the denominator and weakens the overcorrection of faintly illuminated pixels consequently [27]. K value ranges 0-1. The smaller K, the weaker is the influence of the quotient in the Minnaert equation. The increase and decrease the value of C and K are due to the anisotropy reflection into Lambertian reflection to all direction, which on the same objects, the more increasing wavelength, the Lambertian reflection is getting closer to Lambertian reflection [29], and this is the same as our K calculation results.

TABLE I
C AND K COEFFICIENT ON EACH BAND

Coefficient	Band 2	Band 3	Band 4	Band 5	Band 6	Band 7
C	1.3611	0.3008	0.3768	0.1892	0.1526	0.0893
K	0.3781	0.6357	0.6074	0.6977	0.7153	0.7403

C. Visual Analysis

All three topographic correction methods were applied to each band (band 2-7) of Landsat-8. We analyzed visually to find out whether the topographic correction was a success in reducing the effects of slope and aspect or not. The comparison can be seen in Figure 2. The uncorrected images visualized the topographic condition, apparently the same as the IL image. After it was corrected, the topographic condition that previously seems hilly and mountainous, became flat.

As they are analyzed visually, all methods are capable of reducing the topographic effects, but when we see in more detail, C-Correction was less success rather than Minnaert and SCS+C. Band composite of 654 in the C-Correction image shows the slopes facing the solar light are brighter, among other corrections. SCS+C is finer in error reduction compared to Minnaert.

Although all methods can reduce the effects of slope and aspect, several pixels could not be corrected. It is possible to happen in the extremely steepest slope, in which there is no solar energy hits the surface objects. It means the surface reflectance mostly does not represent the object accurately. Although it has been applied the topographic correction, it is almost impossible to bring back the real surface reflectance.

D. Statistical Analysis

Besides visual analysis, statistical analysis is more reliable to find out the success of topographic correction. The examination is conducted by testing standard deviation and correlation value [28]. Hantson and Chuvieco reported the decreasing value of standard deviation indicates the reducing illumination effect on slopes [4].

Table 2 shows the standard deviation of 5,000 samples of surface reflectance as the same as the samples we used in the empirical calculation of IL. All methods have a decreasing value on each band of Landsat-8 image after it was corrected. The declining value of the standard deviation means the surface reflectance value of vegetation objects is getting more homogeneous. All standard deviations of each band are decreasing as it was corrected. SCS+C method has the lowest value among the others.

Correlation analysis between IL and surface reflectance can also be used to determine the success of topographic correction (Table 3). The parameters we considered are the correlation coefficient and slope of the relationship graph. In the analysis, we placed IL as the independent variable, and surface reflectance as the dependent variable. The higher value of correlation means there is a strong relationship between IL and surface reflectance. All bands of uncorrected images have a strong relationship, and it means the illumination is greatly influenced the surface reflectance value. After it was corrected, the correlation is decreasing and getting close to zero value, which means it almost does not have a relationship at all. Besides the correlation value, the slope is also used as an indication of the slope effect [28]. Same with correlation, the slope value is decreasing, and it means the topographic effect has been successfully reduced. SCS+C has half of all bands with the lowest value of correlation and slope values.

TABLE II
THE STANDARD DEVIATION OF VEGETATION OBJECT SAMPLES ON EACH BAND

	Band 2	Band 3	Band 4	Band 5	Band 6	Band 7
Uncorrected	0.0023	0.0060	0.0035	0.0694	0.0284	0.0111
C-Correction	0.0020	0.0044	0.0028	0.0470	0.0200	0.0089
Minnaert	0.0021	0.0046	0.0028	0.0479	0.0201	0.0087
SCS+C	0.0019	0.0038	0.0025	0.0376	0.0156	0.0070

TABLE III
CORRELATION AND SLOPE VALUE OF REGRESSION ANALYSIS BETWEEN IL AND SURFACE REFLECTANCE

	Correlation					
	Band 2	Band 3	Band 4	Band 5	Band 6	Band 7
Uncorrected	0.5417	0.7204	0.6798	0.8201	0.7964	0.7202
C-Correction	-0.0164	-0.0529	-0.0383	-0.0906	-0.0915	-0.0939
Minnaert	-0.1068	0.0280	0.0062	0.0529	0.0695	0.0893
SCS+C	0.0398	0.0459	0.0472	0.0440	0.0321	0.0053
	Slope					
	Band 2	Band 3	Band 4	Band 5	Band 6	Band 7
Uncorrected	0.0072	0.0246	0.0138	0.3267	0.1297	0.0459
C-Correction	-0.0002	-0.0014	-0.0006	-0.0245	-0.0105	-0.0048
Minnaert	-0.0013	0.0007	0.0001	0.0145	0.0080	0.0044
SCS+C	0.0004	0.0010	0.0007	0.0095	0.0029	0.0002

We applied vegetation index transformations on corrected and uncorrected images. Both standard deviation and correlation values were also derived using the same 5,000 sample points. Based on Figures 3, 4, 5, 6, we can see NDVI, AFRI 1.6, and AFRI 2.1 have a slight difference between corrected and uncorrected images; however, MSAVI images are changed significantly.

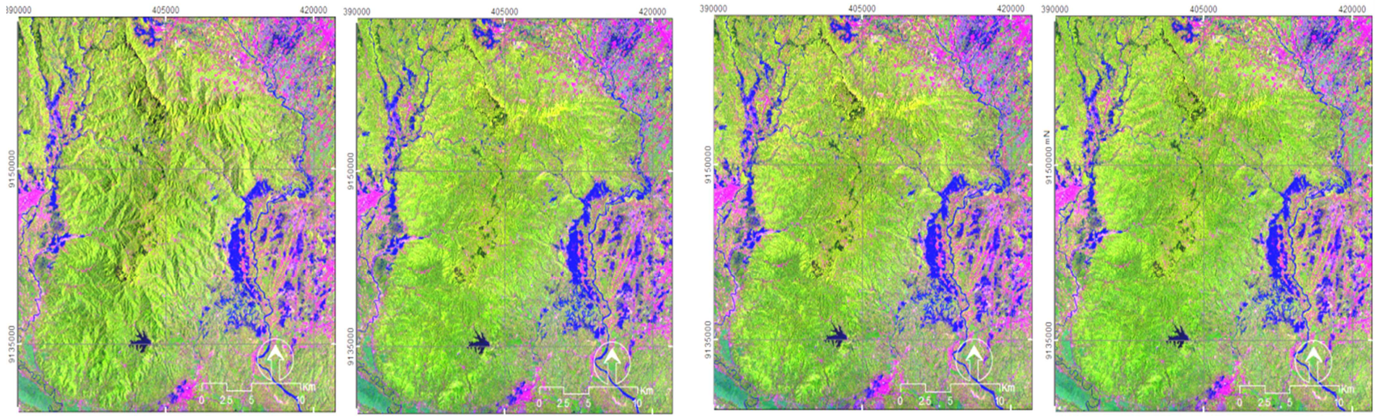
Table 4 and Table 5 show the standard deviation and correlation. The standard deviation, as well as correlation value, are decreasing slightly, except on MSAVI. MSAVI images extremely changed after it was corrected. The correlation on MSAVI images was very high firstly; in contrast, the correlation reduced extremely after they were applied topographic correction (Table 5). Although they have a little reduction, NDVI, AFRI 1.6, and AFRI 2.1 have a lower standard deviation and correlation compared to MSAVI.

TABLE IV
THE STANDARD DEVIATION OF VEGETATION OBJECT SAMPLES ON EACH VEGETATION INDEX

	Standard deviation			
	NDVI	MSAVI	AFRI 1.6	AFRI 2.1
Uncorrected	0.01403	0.11716	0.02218	0.01460
C-Correction	0.01357	0.07864	0.02214	0.01469
Minnaert	0.01363	0.07890	0.02211	0.01455
SCS+C	0.01367	0.06567	0.02200	0.01439

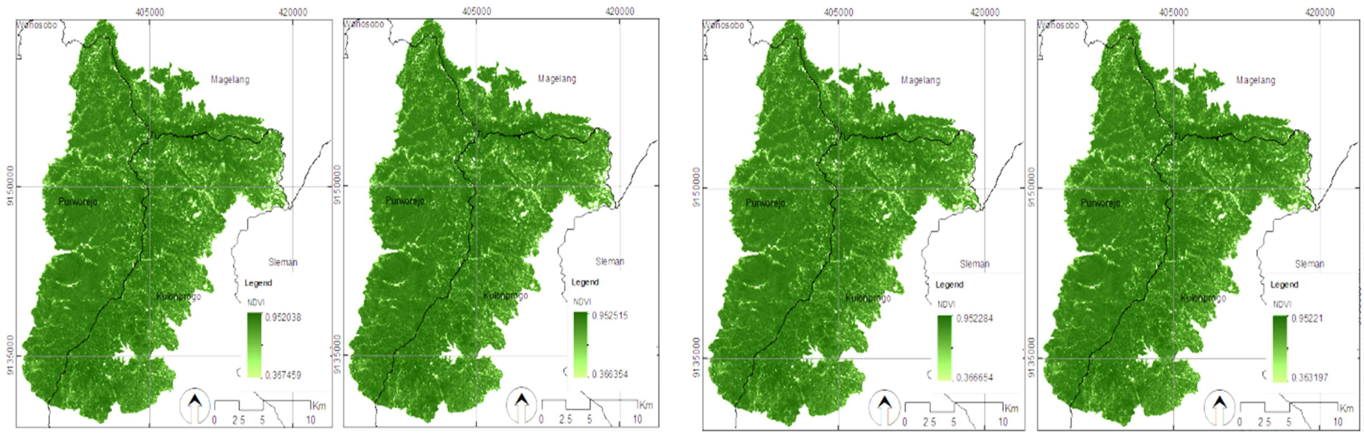
TABLE V
A CORRELATION VALUE OF IL AND VEGETATION INDEX

	Correlation			
	NDVI	MSAVI	AFRI 1.6	AFRI 2.1
Uncorrected	0.20912	0.81195	-0.10302	-0.15466
C-Correction	-0.01372	-0.07790	0.02053	0.04038
Minnaert	0.06307	0.08704	-0.03994	-0.07486
SCS+C	0.00287	0.04352	0.01140	0.02630



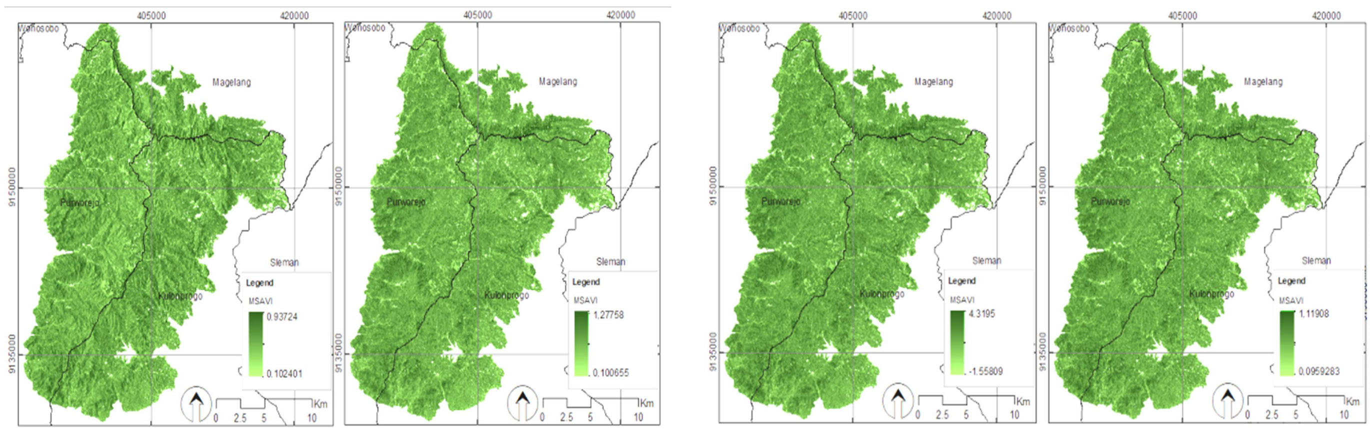
(a) (b) (c) (d)

Fig. 2. 654 color composite of Landsat image (a) uncorrected topographic correction, (b) C Correction, (c) Minnaert, (d) SCS+C



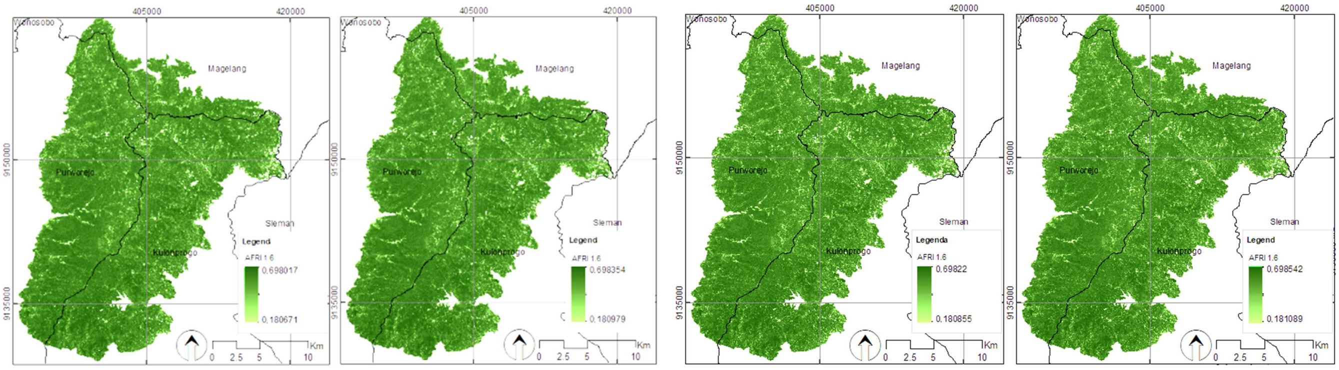
(a) (b) (c) (d)

Fig. 3. NDVI images of study area (a) uncorrected topographic correction, (b) C Correction, (c) Minnaert, (d) SCS+C



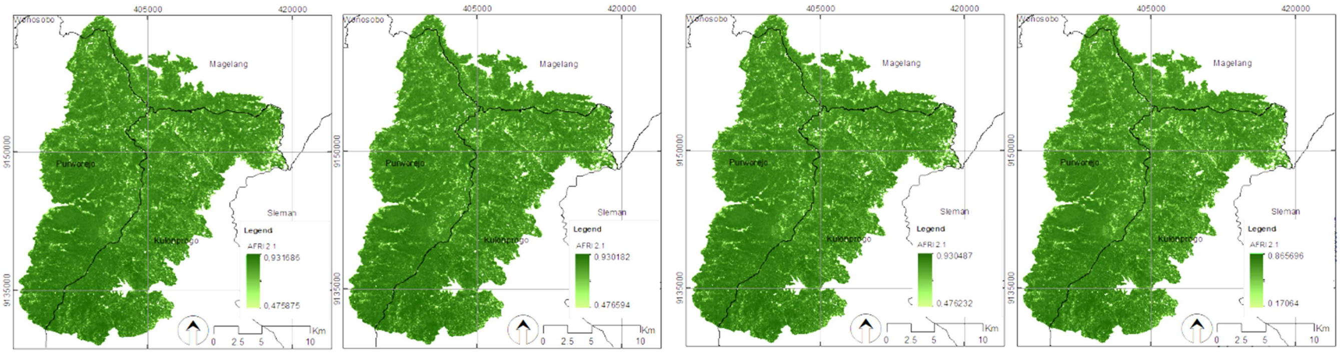
(a) (b) (c) (d)

Fig. 4. MSAVI images of study area (a) uncorrected topographic correction, (b) C Correction, (c) Minnaert, (d) SCS+C



(a) (b) (c) (d)

Fig. 5. AFRI 1.6 images of study area (a) uncorrected topographic correction, (b) C Correction, (c) Minnaert, (d) SCS+C



(a) (b) (c) (d)

Fig. 6. AFRI 2.1 images of study area (a) uncorrected topographic correction, (b) C Correction, (c) Minnaert, (d) SCS+C

The algorithms of vegetation index have different responses on the topographic correction. NDVI, AFRI 1.6, and AFRI 2.1 are categorized as ratio vegetation indices, while MSAVI is a non-ratio vegetation index. NDVI, as the ratio algorithm, can reduce multiplicative disturbance, such as sun illumination, cloud shadows, atmospheric effect, and topographic variation [1]. AFRI 1.6 and AFRI 2.1 that have the same type of algorithm also possess similar characteristics to NDVI.

E. *Canopy Density Estimation Accuracy*

Canopy density field data with a total of 93 data were divided into two groups, 69 data to build the estimation model, and 24 to assess the accuracy. Simple linear regression was used to be the modeling method. Before applying the model, we examined the correlation analysis to find out the relationship between vegetation index and canopy density data. As is seen in Table 6, all the vegetation indices, whether they are corrected or uncorrected of topographic correction, have a strong relationship and could be continued to regression analysis.

Simple linear regression was chosen because it can generalize the model based on samples, although the scatterplot composes non-linear relationships. In the regression analysis, vegetation index was plotted as the independent variable during canopy density data as the dependent variable. Each regression analysis produced a regression equation. These equations were applied to build the canopy density estimation model, with a total of 16 models.

The accuracy of each model was assessed by the maximum accuracy value derived from the Standard Error of Estimate (SE) with a 95% confidence level. We were not only conducted accuracy assessment using all of 24 canopy density data, but also divided it into 3 classes of the density (low, moderate, and high), and assessed the accuracy separately.

TABLE VI
CORRELATION VALUE BETWEEN VEGETATION INDEX AND CANOPY DENSITY DATA

	NDVI	MSAVI	AFRI 1.6	AFRI 2.1
Uncorrected	0.86419	0.69412	0.73288	0.74687
C-Correction	0.86382	0.81017	0.73145	0.74580
Minnaert	0.86407	0.80678	0.73217	0.74648
SCS+C	0.86433	0.80856	0.73142	0.74551

TABLE VII
ACCURACY VALUE OF EACH MODEL

NDVI	Correction			
	Uncorrected	C Correction	Minnaert	SCS+C
SE	8.122	7.960	8.003	7.949
Accuracy (%)	88.740	88.964	88.905	88.980
Increase (%)		0.224	0.166	0.241
MSAVI	Correction			
	Uncorrected	C Correction	Minnaert	SCS+C
SE	10.469	9.662	9.599	10.002
Accuracy (%)	85.486	86.605	86.692	86.134
Increase (%)		1.119	1.207	0.648
AFRI 1.6	Correction			
	Uncorrected	C Correction	Minnaert	SCS+C
SE	12.084	12.050	12.065	12.043
Accuracy (%)	83.246	83.294	83.274	83.303
Increase (%)		0.048	0.027	0.057
AFRI 2.1	Correction			
	Uncorrected	C Correction	Minnaert	SCS+C
SE	12.785	12.770	12.777	12.761
Accuracy (%)	82.276	82.296	82.286	82.308
Increase (%)		0.020	0.011	0.032

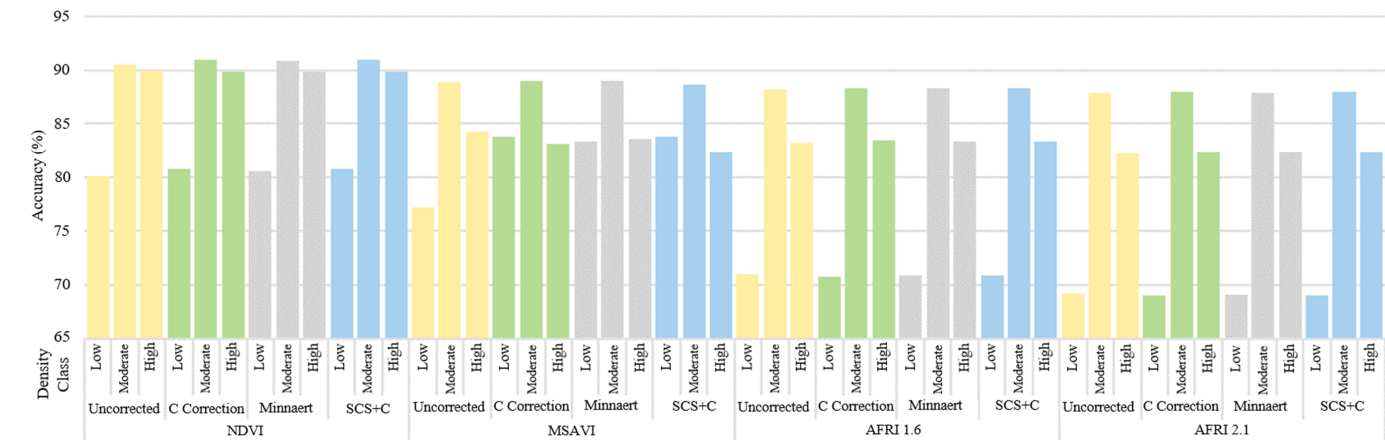
Table 7 shows that all models have a great accuracy value above 80%. Topographic corrections performed their ability to give better accuracy rather than uncorrected models. NDVI has the highest accuracy at all, although it was uncorrected. The mean value of accuracy on NDVI models is 88.897%. Their accuracies became higher after they were corrected, with the mean of the increase is 0.210%, and reached the highest accuracy in the SCS+C method (88.980%).

MSAVI model without topographic correction has an accuracy of 85.486%. Topographic correction increases the accuracy with the increasing mean value of the three models is 0.991%. MSAVI models have the most significant increase in accuracy among the other indices. Even though the mean improvement is less than 1% based on the validation samples, it was improved a lot by looking at the whole image visually. The highest accuracy is the Minnaert method (86.692%). The significant increase in this index is due to the characteristics of the non-ratio index that the uncorrected images showed the topographic condition apparently.

Canopy density models using AFRI 1.6 and AFRI 2.1 have a similar increasing value after they were corrected. AFRI 1.6 and AFRI 2.1 managed to obtain an increasing value of 0.044% and 0.021%, respectively. The mean values of accuracy in 3 correction methods are slightly different, which are 83.920% on AFRI 1.6 and 82.297% on AFRI 2.1. The highest accuracy of AFRI 1.6 and AFRI 2.1 on the SCS+C correction method. This similar accuracy due to both indices is the same type of vegetation index. The short-wave-infrared included in AFRI 1.6 calculation is band 6 (1.6 µm), while AFRI 2.1 used band 7 (2.1 µm). Although AFRI is included in the ratio vegetation index, the accuracy is below the MSAVI. AFRIs has the characteristic of reducing the atmospheric disturbance [26]. Since the observed area is free of atmospheric disturbance, the ability does not have a significant impact. MSAVI that can reduce soil disturbance performed better than AFRIs.

The 24 validation data were divided equally (8 data) into three classes based on the canopy density, consist of below 55%, 55-75%, and above 75% that represent low, moderate, and high canopy density, respectively. The accuracy value was obtained with the same method as the previous assessment.

Figure 7 shows the accuracy of each level of canopy density on each vegetation index and topographic correction method. We can see there is an extreme difference between the accuracies on low and moderate-high canopy density in NDVI and AFRI, but accuracies on MSAVI have a slight difference accuracy on each level. We found that the highest accuracy on moderate canopy density level is on the best correction method of vegetation indices that have been analyzed previously, SCS+C on NDVI and AFRI, and Minnaert on MSAVI. We analyzed that the increase of each level of canopy density depends on the regression analysis that was applied before building the model. The few validation data also affects the results. We recommend using a lot of validation data to do this analysis.



Density Class	NDVI Uncorrected	NDVI C Correction	NDVI Minnaert	NDVI SCS+C	MSAVI Uncorrected	MSAVI C Correction	MSAVI Minnaert	MSAVI SCS+C	AFRI 1.6 Uncorrected	AFRI 1.6 C Correction	AFRI 1.6 Minnaert	AFRI 1.6 SCS+C	AFRI 2.1 Uncorrected	AFRI 2.1 C Correction	AFRI 2.1 Minnaert	AFRI 2.1 SCS+C
Low	80.148	80.786	80.605	80.833	77.273	83.787	83.408	83.862	70.932	70.814	70.874	70.857	69.148	68.96	69.07	69.004
Moderate	90.575	90.925	90.825	90.932	88.832	88.987	88.989	88.617	88.169	88.341	88.264	88.342	87.793	87.909	87.847	87.925
High	89.927	89.805	89.853	89.808	84.227	83.206	83.57	82.33	83.301	83.438	83.374	83.428	82.255	82.402	82.319	82.391

Fig. 7. Accuracy value of canopy density model on each model and canopy density class

Each vegetation index has a different reaction to topographic normalization. The ratio vegetation index type has already corrected the topographic condition based on the algorithm. Indirectly, the ratio algorithm has included the topographic correction method applied without DEM data. Because the bands used in the vegetation index have been corrected, it means the topographic normalization is applied twice. Hence, topographic correction is not essential applied to the ratio vegetation index, but it will be better if this method is applied. Conversely, the non-ratio vegetation index needs the topographic correction because the algorithm does not reduce the topographic effect.

The fundamental difference between the three correction methods is the assumption they used. C-Correction used the Lambertian assumption, which means a perfect diffuse reflection on the surface. This assumption provides overcorrection; hence C coefficient affords to control the overcorrection. Minnaert uses non-Lambertian assumptions due to the not applicable Lambertian assumption on the natural surface on earth. The non-Lambertian function was applied using the K coefficient, where the smaller K, the more non-Lambertian surface appears.

SCS+C method achieved the best accuracy of the canopy density model in NDVI, AFRI 1.6, and AFRI 2.1. This result is supported by the term SCS+C method that considers the canopy geometry aspect, which erects the canopy objects. Meanwhile, canopy objects in C-Correction and Minnaert still follow the slope condition.

C-Correction is the second highest of accuracy in all vegetation index. Minnaert is the lowest accuracy in all models, except in MSAVI that reached the highest accuracy. In overall, increasing accuracy in C-Correction and Minnaert has a slightly different, according to the value of NDVI, AFRI 1.6 and AFRI 2.1 are 0.059%, 0.021%, and 0.009%, respectively. It means the Lambertian assumption that is used in C-Correction is slightly different from the non-Lambertian of Minnaert because both methods use C and K coefficient, respectively, to avoid the overcorrection.

IV. Conclusion

The topographic correction can reduce slope and aspect effects according to visual and statistical analysis using standard deviation and correlation analysis. Overall, topographic correction can increase the accuracy of canopy density estimation. Ratio vegetation indices, such as NDVI and AFRIs, are not significantly affected due to their ability to reduce the several disturbances, including illumination and topographic effects, although it would be better if applying the topographic correction. MSAVI, the non-ratio vegetation index, is very significantly affected by the topographic correction. NDVI is the best index to estimate canopy density, whether it was corrected or not. Even though it has been topographically corrected, AFRI 1.6 and AFRI 2.1 have lower accuracy than MSAVI due to the ability of MSAVI to reduce soil disturbance. We found that SCS+C is the most consistent method among C-Correction and Minnaert according to the visual and statistical analysis of every single band and vegetation index, and the accuracy analysis of canopy density estimation.

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