AGROFORESTRY TREE DENSITY ESTIMATION BASED ON HEMISPHERICAL PHOTOS & LANDSAT 8 OLI/TIRS IMAGE: A CASE STUDY AT CIDANAU WATERSHED, BANTEN-INDONESIA

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ABSTRACT:

The Cidanau watershed is the only watershed in Indonesia that implements Payment for Environmental Services (PES) for farmers who can maintain tree/stand density of 500 trees/hectare on their land. Payments are made upon the verification on the field by the project supervisor. This method requires a lot of time and costly, so it is necessary to build more efficient indirect methods, including using satellite imagery or camera data. The aim of this study is to understand Landsat OLI 8 and hemispherical photo can estimate tree density in the farmer's agroforestry stand. To obtain tree density, the number of trees with diameter more than 10 cm in 50 plots (50 m x 50 m) were counted. Some predictor variables were utilized, such as Leaf Area Index (LAI) based on hemispherical photos, Normalized Difference Vegetation Index (NDVI), Forest Cover Density (FCD), as well as NDVI and FCD which were enhanced with topographic correction. The imagery used was Landsat 8 OLI acquired on July 5, 2015, with Path/Row 123/64. The relationship between tree density and predictor variables was done using linear regression analysis. Prior to regression analysis, normality (Kolmogorov Smirnov/K-S), heteroscedasticity (Glejser test) and auto correlation (Durbin Watson) test were performed. The results of the analysis showed that tree density was estimated better with hemispherical photos-based LAI, with determination coefficient of 80.6%. Meanwhile, estimation using NDVI and FCD has lower determination coefficient. Even though, the use of topographic correction had been able to increase the determination coefficient of the regression relationship between tree density and FCD, from 4.64% to 35.18%.

1. INTRODUCTION

Cidanau River is one of the rivers in Banten Province which is used for domestic and industrial drinking water, which is managed by a private water company PT. Krakatau Tirta Industri (PT. KTI). The communities in this watershed are mostly rice farmers in flat areas and agroforestry farmers in hilly areas. Agroforestry is a farming technique that combines trees with food crops (Nair, 1993). Continuous water supply from the river depends on the ability of the watershed to store water throughout the year. This depends greatly on the conditions of land cover. The better the vegetation closure, the better the watershed will store water. This condition is indicated by the coefficient value of river regime, which is a ratio between maximum and minimum discharge (Qmax/Qmin), that is not greater than 15 (Pantouw et al., 2013).

To maintain extensive tree vegetation closure, PT. KTI runs a Payment for Environmental Service (PES) program, where farmers will get a payment if they can maintain a tree density of 500 trees/hectare in their agroforestry land. Payment will be made after verification in the field by the assessor/project supervisor. Field work assessment usually takes a long time and high costs. Therefore, efficient indirect methods need to be found, including using satellite image data and cameras. This research aimed at understanding how Forest Cover Density (FCD) and hemispherical photos-based Leaf Area Index (LAI) can estimate tree density in the farmer's agroforestry stand.

Forest Canopy Density (FCD) is a quantitative value that represents the degrees of forest density and expressed by the percentage. It is an important variable related to the forest degradation, as a basic information of possible management intervention (Azizi et al., 2008). Estimation of FCD using satellite imagery has been developed by Rikimaru (Rikimaru et al., 2002) based on 4 types of indices, namely temperature, shadow, vegetation and open land index based on satellite image data. FCD has been tested in many aspects of forest management, including estimating forest density (Banerjee, et al., 2014; Anand et al., 2018), and basal area and predominant height (Baynes, 2004). Meanwhile, Muhammad et al. (2014) and Tohir, et al. (2014) studied pine forests and community forests with teak dominance, respectively, and both results showed a good accuracies. In both cases the tree stand structure was relatively uniform, and until now there is no literature yet on the use of FCD in mixed/heterogeneous ecosystems, such as agroforestry ecosystem. Moreover, most of the Landsat images for FCD identification were not topographically corrected. The current research is the first attempt to calculate tree density using FCD for the agroforestry ecosystem with topographically corrected Landsat images.

Hemiview photos have been used to estimate Leaf Area Index (LAI) (Anne et al., 2006; Lhotka & Loewenstein, 2006; Chen et al., 1991), but the use on estimating tree density in agroforestry stand is very limited. In Indonesia, estimations of stand density using Hemiview photos carried out by Muhammad et al. (2014) in pine stands and Tohir, et al. (2014) in community plantation forests dominated by teak trees. The aim of the research is understanding how

Normalized Vegetation Index (NDVI), Forest Cover Density (FCD) and hemispherical photos-based Leaf Area Index (LAI) can estimate tree density in the farmer's agroforestry stand. Meanwhile the objectives of the research are as follows : (1) to calculate and compare stand density using NDVI, FCD and Hemispherical photos-based LAI for the agroforestry ecosystem with topographically corrected Landsat images and (2) to clarify the mathematical relationship between tree density values with NDVI, FCD and Hemispherical photos-based LAI

2. MATERIAL AND METHOD

2.1 Study site

The study was conducted in the Cidanau Watershed, Serang District and Pandeglang District, Banten Province, Indonesia. Geographically, the Cidanau watershed is located between 07o 07 '30" - 06 o 18 '00" South Latitude and 105o 49 '00" -106 o 04 '00" East Longitude. The Cidanau watershed has an area of 22,620 hectares. The watershed landscape is mountainous at upstream, flat in the middle and relatively gentle slope a the downstream (Figure 1). Land cover of upstream is forests and various types of agroforestry ecosystem. In the middle part is food crops and in the downstream is agroforestry. The majority of the people living in the area are farmers.

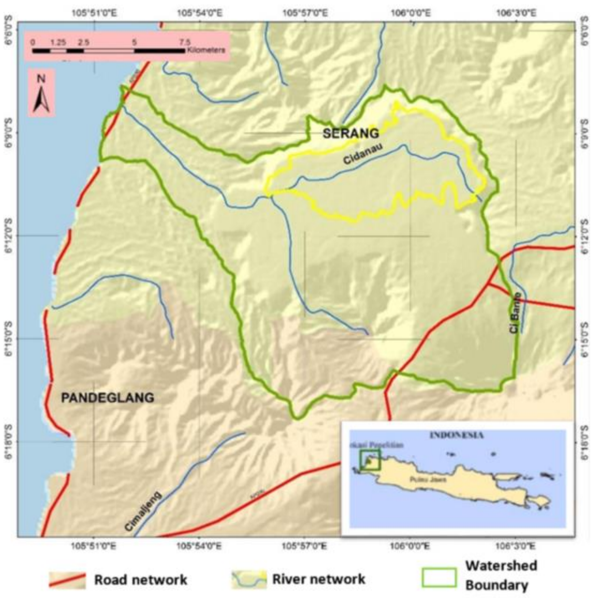


Figure 1. Study area: Cidanau Watershed

2.2 Methods

2.2.1 Survey plot and measurement methods

Survey plot locations were distributed purposively based on 10 categories of FCD, ranging from low FCD (0-10%) to very high FCD (90-100%). A total of 50 plots (50 m x 50 m) were established for hemispherical photographs and tree stand density measurement. In addition, 50 additional plots from secondary data of the previous research were used for tree density survey. Hemispherical view photographs were taken from the centre of the plot at position of $\pm$ 1.5 m height from the ground, using DSLR camera mounted with fisheye lens. Tree species and number of trees with diameter more than 10 cm within the plot were counted.

2.2.2 Topographic correction

The Landsat 8 OLI/TIRS Path/Row 123/64, taken on 5 July 2015 image was topographically corrected based on Tan algorithm (Tan *et al*., 2013), which also adopted by Hudjimartsu (2017) to reduce the effect of sun illumination difference. Illumination condition and corrected reflectance model were calculated based on equation as follows:

$$Ic = \cos\phi \cos slope + \sin\phi \sin slope \cos(\theta - aspect) \quad (1)$$

$$\lambda_{corrected} = \lambda_{uncorrected} - \beta(ic - \phi) \quad (2)$$

Where :
ic : Illumination condition, ϕ : Zenith angle, θ : Azimuth angle, β is the slope of the linear regression between illumination condition of each pixel and reflectance of the same object.

2.2.3 Forest Cover Density (FCD)

Forest Cover Density algorithm was develop by Rikimaru (Rikimaru *et al*., 2002). The FCD is representing the proportion of tree cover and land surface under the canopy. Its value range from 0 to 100%. Value of 0% means there is no tree canopy, conversely 100% means all land surface is covered by tree canopy. In this research, the FCD was estimated topographical corrected Landsat images, by using FCD mapper. Two FCD calculations were performed, namely before and after topographical correction. Topographic correction will eliminate the slope and aspect effect, because the pixel reflectance has been corrected with illumination conditions. The illumination correction was more accurate, since it was considering sun angle and sun azimuth for every pixel of the image, rather than sun angle and sun azimuth of midpoint of the scene written in the Landsat image metadata.

2.2.4 Leaf Area Index (LAI) and hemispherical view

Leaf Area Index is projected area of green canopy per unit of horizontal ground surface area (Casella et al., 2013). Hemispherical view photographs were taken by Nikon camera mounted with fisheye lens. The LAI was calculated by using Hemiview canopy analysis software.

Figure 2. Hemispherical view acquisition and its photograph

2.2.5 Normalized difference vegetation index (NDVI)

NDVI was calculated based on an equation as follows:

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}} \tag{3}$$

Where :
NDVI = Normalized Difference Vegetation Index
NIR = Near Infra red band (Landsat 8 OLI, 0.851 - 0.879 μm)
Red = Red band (Landsat 8 OLI, 0.636 - 0.673 μm)

2.2.6 Statistical Analysis

Linear regression analysis between tree stand density with FCD and LAI were conducted. Prior to this analysis, classical assumption was checked, including the assumptions of normality (Kolmogorov Smirnov/K-S), heteroscedasticity (Glejser test) and auto correlation (Durbin Watson) by using software IBM SPSS Statistics 22.

3. RESULTS

3.1 Topographic correction

Topographic correction could reduce the influence of illumination differences as presented in Figure 3. Further observation to the pixel reflectance of every bands in the Landsat 8 OLI showed that the topographic correction reduced the effect of different illumination. Before topographic correction, the pixel reflectance of the same object increased by the increasing illumination condition. Meanwhile, after the correction, the same object most likely have the same spectral reflectance. Figure 4 to Figure 9 presents the response of pixel reflectance some bands of Landsat 8 OLI due to different illumination before and after topographic correction.

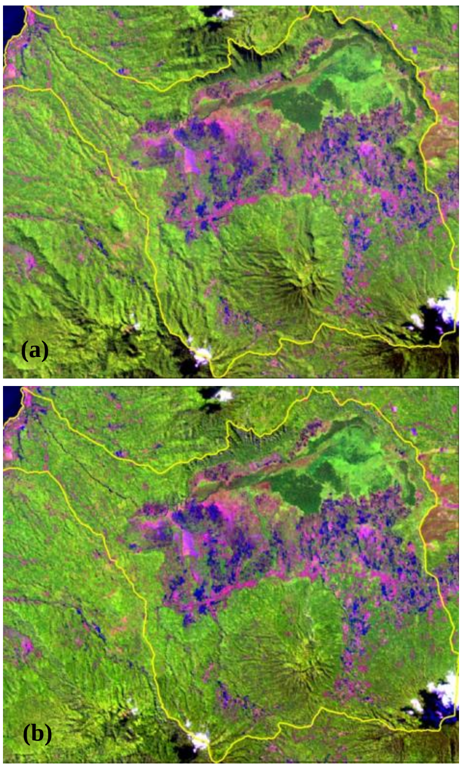


Figure 3. Landsat 8 OLI image comparison (a) before and (b) after topographic correction

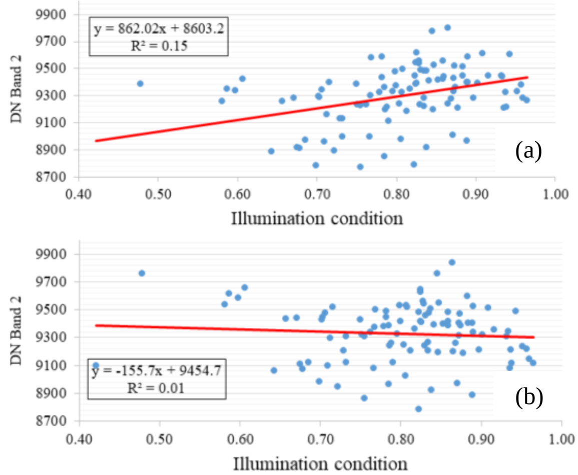


Figure 4. Reflectance of band 2, (a) before and (b) after topographic correction

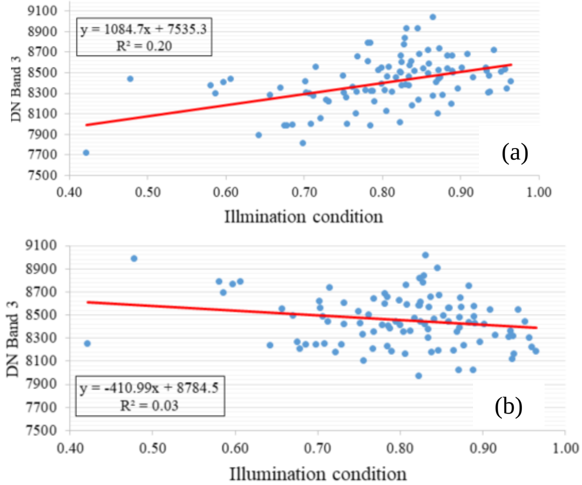


Figure 5. Reflectance of band 3, (a) before and (b) after topographic correction

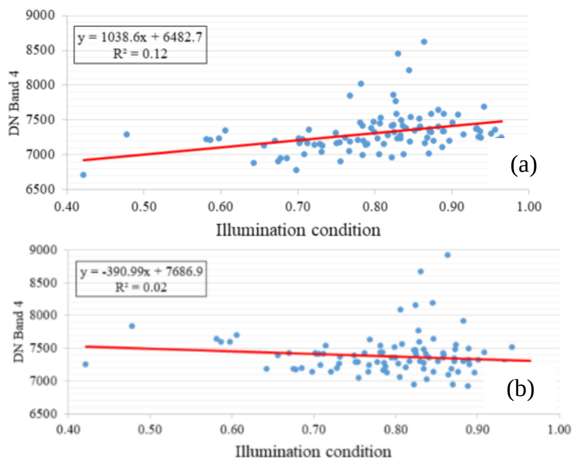


Figure 6. Reflectance of band 4, (a) before and (b) after topographic correction

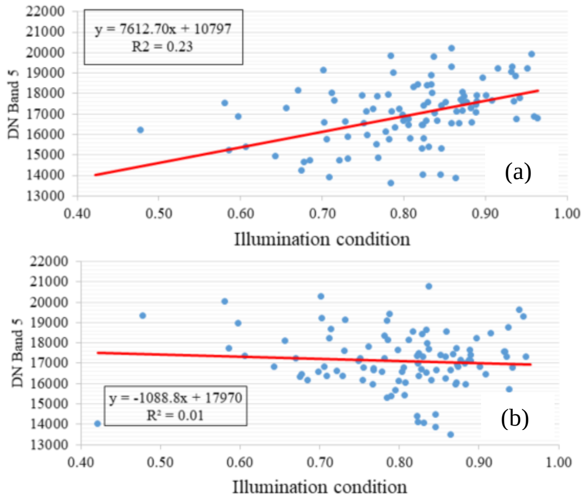


Figure 7. Reflectance of band 5, (a) before and (b) after topographic correction

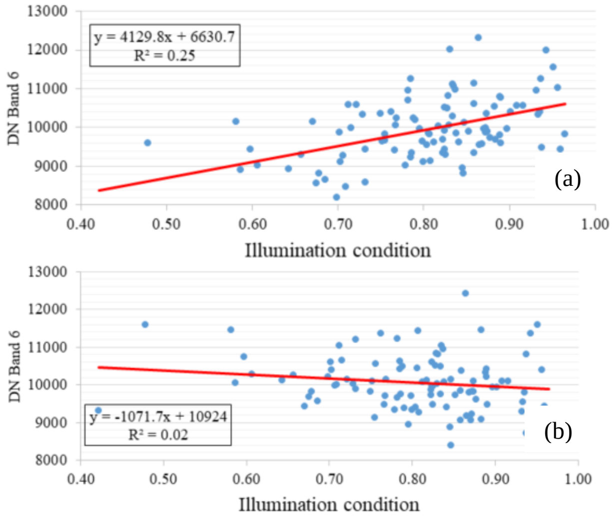


Figure 8. Reflectance of band 6, (a) before and (b) after topographic correction

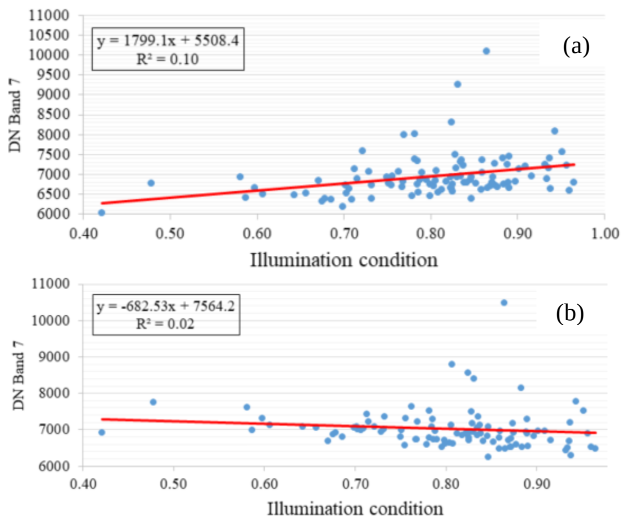


Figure 9. Reflectance of band 7, (a) before and (b) after topographic correction

3.2 NDVI before and after topographic correction

Visually, topographic correction was not influence the NDVI significantly (Figure 10). It could be explained also by the value of statistic parameter of the images, whereas the value was only slightly changing (Table 2). Since NDVI was based on ratio bands, the topographic correction did not have much effect because it's avoiding each other.

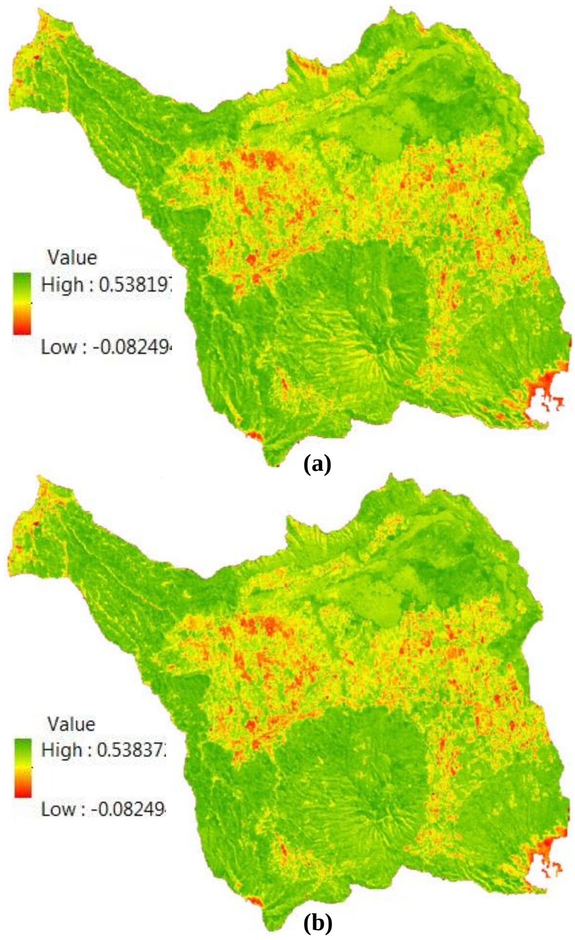


Figure 10. Value of NDVI, (a) before and (b) after topographic correction

Table 1.Statistical parameter comparison of NDVI before and after topographic correction

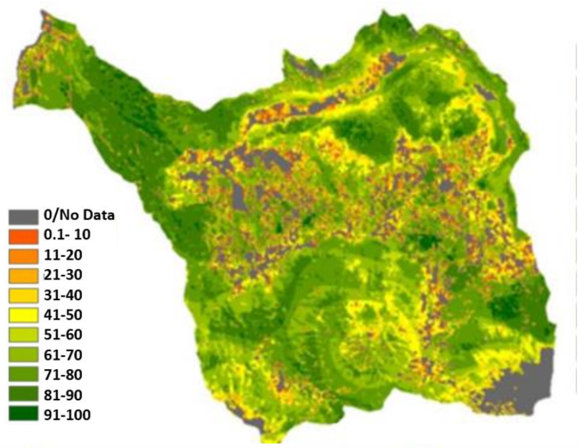
NDVI	Before topographic correction	After topographic correction
Minimum	-0.0825	-0.0825
Maximum	0.5382	0.5384
Average	0.201	0.203
Std. Dev.	0.184	0.186

3.3 FCD before and after topographic correction

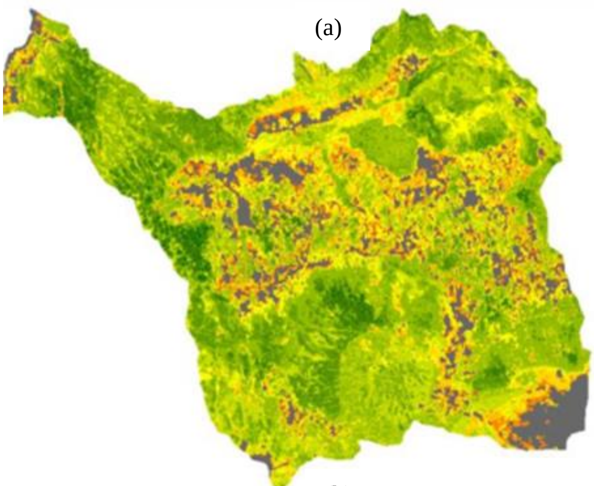
Since the topographic correction reduce the influence of slope & aspect, the correction also affecting the value of FCD (Figure 11). The FCD before topographic correction tended to be higher in comparison with FCD after correction. This is shown in the Table 2 that the maximum FCD increased, while the average, median and standard deviation of FCD decreased.

Table 2.Statistical parameter comparison of FCD before and after topographic correction

FCD	Before Correction	After Correction
Minimum	0%	0%
Maximum	91%	94%
Average	55.17%	50.09%
Std. Dev.	27.92%	23.95%



(a)



(b)

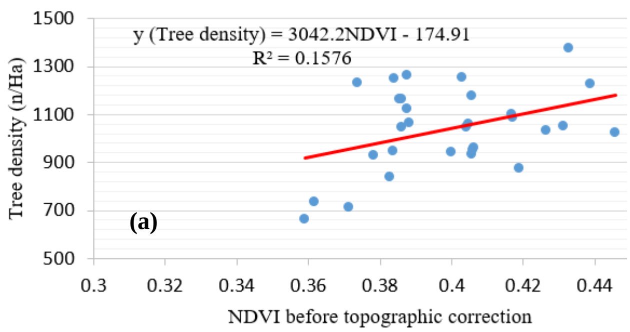
Figure 11. FCD value, (a) before and (b) after topographic correction

3.4 Relation of Tree density, FCD and LAI

Upon classic assumption check of linear regression with prior normality, heteroscedasticity, and autocorrelation, three linear regression equations were performed.

3.4.1 Linear regression between tree density and NDVI before and after topographical correction

Even though the correction of topographic have not much influence on the NDVI, the correction could improve the coefficient determination (R^2) of the regression analysis from 0.1576 to 0.2962, between tree density and NDVI (Figure 12).



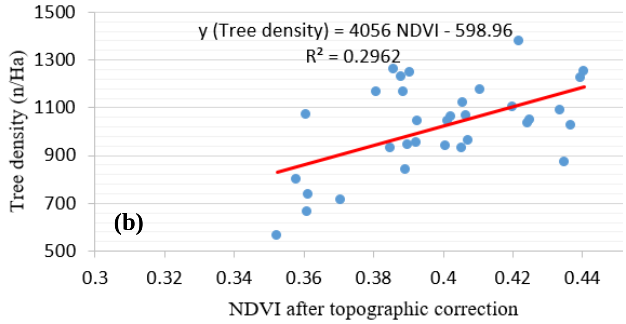


Figure 12. Regression between tree density and NDVI, (a) before and (b) after topographic correction

3.4.2 Linear regression between tree density and FCD before and after topographic correction.

Figure 13 shows the regression between tree density and FCD before topographic correction. The graphic shows a negative relationship between FCD and tree density, moreover, the relation was very weak (R^2 = 0.046.). This is contrary to the results of the research conducted by Tohir, et al. (2014) and Muhammad, et al. (2014), whereas the FCD in line with the tree density, regardless the difference stand structure.

After topographic correction, the relationship between tree density and FCD changed to positive, the more FCD increases, the higher the density of the tree. In addition, the coefficient of determination (R^2) also increases from 0.0464 to 0.3518 (Figure 13).

3.4.3 Linear regression between tree density and LAI

In comparison of employing FCD, the estimation of tree density using LAI was better. Figure 14 shows a very close relationship between tree density and LAI with a determination coefficient (R^2) reaching more than 80%.

4. CONCLUSION

Topographic correction can reduce the effects of different illumination and could improve the quality of satellite image data. Therefore, it can increase the relationship between tree density and FCD as well as NDVI.

This study also concluded that Hemispherical photos-based LAI is a better variable than NDVI and FCD for estimating tree density in agroforestry ecosystem. Therefore, this method is recommended as a proxy to calculate tree density in complex stand structure, such as agroforestry ecosystem.

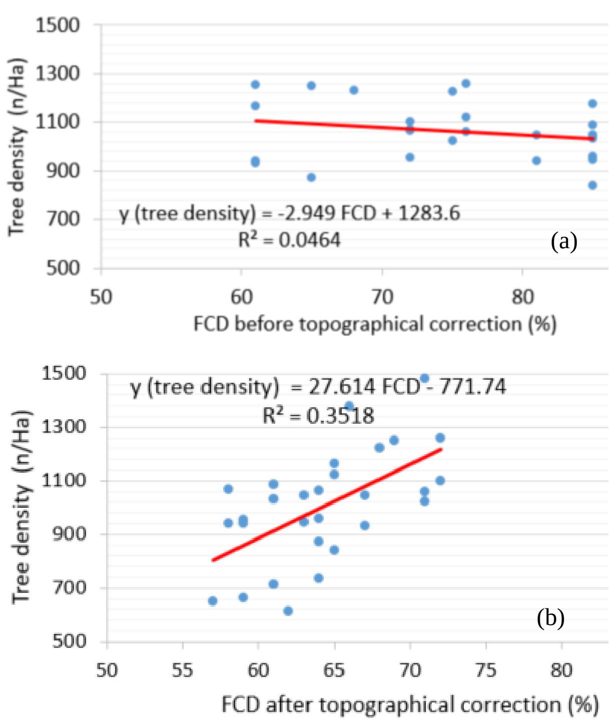


Figure 13. Regression between tree density and FCD, (a) before and (b) after topographic correction

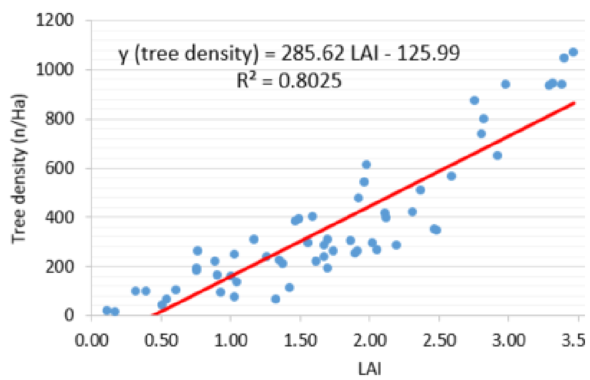


Figure 14. Regression between tree density and LAI derived from hemispherical view

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