The Utilization of Landsat 8 Multitemporal Imagery and Forest Canopy Density (FCD) Model for Forest Reclamation Priority of Natural Disaster Areas at Kelud Mountain, East Java

S Himayah1, Hartono2, P Danoedoro3

1 Remote Sensing, Geography Faculty, Gadjah Mada University, Yogyakarta, Indonesia 55281
2 Cartography and Remote Sensing, Geography Faculty, Gadjah Mada University, Yogyakarta 55281
3 PUSPICS, Yogyakarta, Indonesia 55281

Abstract. Remote sensing has the advantage in terms of temporal resolution that can be used to examine changes of the forest canopy density as occurred in Kelud Mountain after the eruption of 2014. Canopy density changes then used as a consideration for forest reclamation priority. This study aims to assess the ability of Landsat 8 multitemporal imagery and Forest Canopy Density (FCD) modeling for canopy density changes at Kelud forest before and after the eruption, as well as take advantage of the canopy density changes from FCD and biophysical condition of forest to make a forest reclamation priority. This research using a Landsat 8 imagery (26 June 2013 and 4 September 2015). The method that used is FCD modeling to obtain canopy density. Forest reclamation priority is determined based on the canopy density change after the eruption and biophysical factors such as slope, soil fertility and native vegetation. Landsat 8 can used to determine the forest canopy density of Kelud before and after eruption with an accuracy of 83.73% and 81.14%. Kelud forest reclamation priorities are divided into nine classes based on priority level. The most prioritized class is 1a with an area of 865 ha and class 1b with an area of 2.085 ha. Then class 1c (0 ha), 1d (413 ha), and 1e that most dominate (5.454 ha). Beside that, there is class 2a (1.900 ha) and 2b (243 ha), and the last is class 3a (467 ha) and 3b (1.172 Ha).

1. Introduction
Temporal resolution of remote sensing imagery can be used to monitor phenomena or objects changes within a certain time. Vegetation includes as an easy objects to identify from remote sensing imagery. Infrared band that owned by Landsat 8 system is a band that is most sensitive to vegetation. The vegetation reflection at infrared band are often used to calculate the vegetation index. Vegetation index is then developed to expand the remote sensing studies of vegetation.

The advantages of multitemporal remote sensing imagery and reflection of vegetation in the near infrared band makes it possible to do research on forest canopy density changes as occurred in the forest of Mount Kelud after the eruption. Forest Canopy Density (FCD) is a biophysical analysis model that can be used to analyze a forest canopy density changes after the eruption with involving four factors:
the vegetation, bare soil, shadow, and temperature. Data of percentage per pixel on four factors obtained from advance vegetation index (AVI), bare soil index (BI), shadow index (SI), and thermal index (TI), [11].

Forest degradation should be addressed to restore its functionality. One attempt for recovery of forest function is with forest reclamation. FCD Model through Landsat 8 multitemporal can facilitated the implementation of the reclamation. Analysis of changes in canopy density through FCD Model and forest biophysical conditions then used to make a priority of forest reclamation.

1.1 Study area
This study area located at a forest of Mount Kelud, administratively belonged to Kediri, Blitar, and Malang, East Java, Indonesia. The peak of Mount Kelud is located at an altitude of 1731 meters above sea level, and the forest of Mount Kelud has an area of 13.381 hectares. Mount Kelud included in stratovolcano type with explosive eruptions characteristics, and last erupted on February 13-14, 2014. Forest of Mount Kelud is a tropical rain forest located in 112°14'00”-112°22'20”E and 7°51'40”-8°0'40”L. According to the height of the sea surface, the forests of Mount Kelud divided into the low rain forest zone (0-1000 meters above sea level) and the middle rain forest zone (1000-3300 meters above sea level). Forests of Mount Kelud selected as the study area because it suffered damage caused by the eruption.

1.2 Data
This study is using Landsat 8 image acquired on 23rd June 2013 and 4th September 2015. Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) images consist spectral bands with a spatial resolution of 30 meters for Bands 1 to 7 and 9. The resolution for Band 8 (panchromatic) is 15 meters and Thermal bands 10 and 11 are collected at 100 meters. Landsat 8 Operational Land Image (OLI) and Thermal Infrared Sensor (TIRS) images consist of eleven bands: coastal aerosol (0.43 - 0.45 µm), blue (0.450 - 0.51 µm), green (0.53 - 0.59 µm), red (0.64 - 0.67 µm), near-infrared (0.85 - 0.88 µm), SWIR 1(1.57 - 1.65 µm), SWIR 2 (2.11 - 2.29 µm), panchromatic (PAN) (0.50 - 0.68 µm), cirrus (1.36 - 1.38 µm), TIRS 1 (10.6 - 11.19 µm) and TIRS 2 (11.5 - 12.51 µm). Beside that, this study also using ASTER GDEM scene S08E112 and S09E112, image acquired on 17th October 2011.

2. Methods
2.1 Forest Canopy Density Model
Forest Canopy Density (FCD) is a method for estimating forest canopy density by considering vegetation, bare soil, temperature, and shadow. FCD using biophysical phenomena modeling such as Advanced Vegetation Index (AVI), Bare Soil Index (BI), Shadow Index (SI) and Thermal Index (TI) (Rikimaru, 2002). These indices is using band 2 (blue), band 3 (green), band 4 (red), band 5 (near infrared), band 6 (SWIR 1), band 7 (SWIR 2), dan band 10 (TIR1) of Landsat 8 imagery.

Advanced Vegetation Index (AVI) is one of the indices that examine the characteristics of the vegetation chlorophyll. The index uses the equation:

\[ AVI = \frac{((\text{Band}5 + 1) \times (256 - \text{Band}4) \times (\text{Band}5 - \text{Band}4))^{1/3}}{1/3} \] ........................... (2.1)

Bare Soil Index (BI) formulated using SWIR 1 band, NIR band, red band, and blue band. This index is using equation:

\[ \frac{((\text{B6}+\text{B4})-(\text{B5}+\text{B2}))}{((\text{B6}+\text{B4})+(\text{B5}+\text{B2}))} \times 100 \] ........................ (2.2)

Shadow Index (SI) test a shadow characteristic by utilize a spectral information from forest shadow and thermal information, with an equation:

\[ SI = \frac{(256 - \text{Band}2 \times (256 - \text{Band}3) \times (256 - \text{Band}4))^{1/3}}{1/3} \] ........................ (2.3)

Thermal Index (TI) is based on two kind of factor that affect cold relativity condition inside the forest. The first one is shielding effect from forest canopy that blocking and absorbing energy from the sun.
The second one is leaf area surface which reduces heating (Rikimaru, 2002). Temperature data then used to separating a soil and a non-tree shadow. Equation that use for Thermal Index (TI) is:

\[ T = \frac{K_2}{\ln(K_1/L_\lambda + 1)} \]  

(2.4)

Explanation of FCD four indices combination is:

| Index                                | High-FCD | Middle-FCD | Grass land | Bare land |
|--------------------------------------|----------|------------|------------|-----------|
| Advanced Vegetation Index (AVI)      | High     | Middle     | High       | Low       |
| Bare Soil Index (BI)                 | Low      | Low        | Low        | High      |
| Shadow Index (SI)                    | High     | Middle     | Low        | Low       |
| Thermal Index (TI)                   | Low      | Middle     | Middle     | High      |

Source: Rikimaru, 2002

If the value of AVI higher then most likely a value of FCD was high too. Low AVI value and high BI value means bare land area, meanwhile low BI value means a vegetation area. SI have a low value for objects such as bushes and open ground area. SI value indicates impairment along with a value of FCD, meanwhile TI is increased with a reduction of vegetation and have a high value in bare land areas. Vegetation Density (VD) is a proportion of soil surface that enclosed by plant crown projection. VD result from Principal Component Analysis (PCA) method because AVI and BI has a negative correlation.[11];[4].

SSI is the histogram value of SI that has been adapted by TI to distinguish the forest and vegetation ground such as shadows and surface temperature. Areas that have zero value of SSI indicates a forest with a lowest shadows and a 100 SSI value indicates forests that is likely to have the highest shadow value. With the development of the SSI, then will be able to distinguish between vegetation canopy and vegetation in the soil. [7]; [11] Integration of VD and SSI produces the value of forest canopy density. Forest canopy density index value is calculated using the equation:

\[ FCD = (VD \times SSI + 1)^{1/2} - 1 \]  

(2.5)

The integration of these models results the canopy density of data per pixel. FCD percentage value from 0% to 100%. 0% indicates a lack of coverage of the canopy and the area is dominated by bare land. Along with the greater percentage of the value of the FCD, the pixel area more covered by canopy.

Forest canopy density modeling before and after the eruption then tested using the Standard Error of Estimation (SEE). SEE is a test method that considering the difference between the accuracy of canopy density from FCD model with actual density from field measurement. Field measurements to obtain the actual canopy density was conducted in March 2016, with the total number of sample are 41 plots. FCD modeling accuracy test results that have is further used to analyze changes of canopy density after the eruption of 2014.

2.2 Forest Canopy Density Changes
Canopy density modeling map results from FCD in 2013 and 2015 are used to detect canopy density changes with a combine methods in ArcGIS 10.2. Combine is a raster overlay method, in which each pixel in the same geographical position with two different time (or in this case may also be called cell) analyzed and then given a new identity.

2.3 Forest Reclamation Priority
Forest reclamation is an attempt to repair or restore a damaged land and vegetation in order to function to its optimum. (Permenhut 48, 2013 on Guidelines for the Forest Reclamation of Natural Disasters Area). Priority of reclamation created to facilitate the implementation of the reclamation. Priority refers to the inventory based on changes in the forest canopy density from FCD result, slope derived from
DEM data, as well as the fertility of the soil and vegetation conditions as the results of field measurements. Utilization of remote sensing in the protected forest reclamation priority of Mount Kelud did not involve biophysical factors such as land use, forest functions, and climate. This is because the land use in this study is focused only on protected forest areas which is has a tropical climate.

2.3.1 Topographic Form
Slope classification obtained from the DEM data by using the 3D Analyst tools in ArcGIS software. Topographic are qualitatively termed as landscape, while quantitatively expressed in grade slope (%), namely: Class I (0-8%), Class II (9-15%), Class III (Kinda Steep 16-25%), Class IV (26-45%), Class V (> 45%). Topographic considered as a biophysical parameter in the inventory of forest reclamation due to its relevance in terms of accessibility of forest reclamation. Flat areas can facilitate the implementation of the reclamation because its easier to reach, and conversely, areas with steep slopes will be difficult for reclamation because it is difficult to reach. In addition, the flat slopes and ramps will be easier for field measurements.

2.3.2 Soil Fertility
Soil fertility is obtained based on field measurements were conducted in March 2016. The parameters used to determine the soil fertility is color, texture, and pH.

2.3.3 Native Vegetation
Vegetation condition before the occurrence of a natural disaster can be represented through the canopy density. While the native vegetation can be expressed by a species of vegetation that are dominant in the study area. Plant species in the forests of Mount Kelud which includes as an area of lowland forest (<1,000 meters above sea level) consists of Dendrocalamus asper, Croton argyratus, Ficus infectoria, Laportea stimulant, Villebrunea rubescens, Ostodes paniculata, Altingia, Bischofia, Castanopsis, Ficus, Gossampinus and plants of the Leguminosae family [10]. Lower montane forests or middle rainforests (> 1000 meters above sea level) generally have the type of dominant vegetation such as Lithocarpus, Castanopsis, Altingia excelsa, Dacrycarpus imbricartus, Engelhardia spicata, Schima wallichii, Cyathea spp, and Weinmannia blumei [12; 5;8]. Native vegetation type compared to other types of vegetation after the eruption. So then it can obtained species that survives, or whether there is a change of the dominant species, or perhaps there are species disappearing.

2.3.4 Determining the Priority Class of Forest Reclamation
Map of canopy density changes after the eruption is overlayed with a slopes map, also with the information that obtained from the field measurements. Factors to be examined first is the forest canopy, and then topography, soil fertility, and vegetation type. The results of these analysis will be used to make a priority concept of forest reclamation. Variables such as canopy density changes obtained from the FCD modeling, slope obtained from ASTER GDEM image processing, while the fertility of the soil and vegetation changes obtained from field work.
Class of reclamation priority is divided into three, namely 1, 2, and 3. The division of this class is based on canopy density changes: reduced, stable, and increased. Areas which is canopy density reduced is the most prioritized area. All three classes are then subdivided into several sub-class with considering a slope (topography), the fertility of the soil and vegetation conditions.

3. Results and Discussion
3.1 Forest Canopy Density Model
Advanced Vegetation Index (AVI), Bare Soil Index (BI), Shadow Index (SI) and Thermal Index (TI) processed using FCD Mapper software to obtain a canopy density in percentage (%). AVI and BI
calculation result a Vegetation Density (VD), whereas SI and TI calculation result a Scaled Shadow Index (SSI). VD and SSI then analyzed to make a FCD estimation in percentage (%) which represent a canopy density for each pixel. FCD in 2013 (before eruption) and in 2015 (after eruption) are reclassified into 10 classes to make a change detection process easier.

Canopy Density of Mount Kelud Map is using color symbol adjusted to FCD Mapper results, namely blue, cyan, magenta, red, orange, yellow, and gradation of green. The appearance of canopy density before the eruption dominated by the density of 72-80% with an area of 4698.90 ha. This density classes represent the condition of forest with a canopy cover 71-80% of the area of pixels with different strata of stands clearly visible as well as the heterogeneity of types is increasing. Meanwhile, the most visible appearance is the red color (21-30%) which is shaped elongated resembling mountain slopes.

After the eruption, the percentage 1-10% of canopy density is wider than before the eruption. The canopy density of 1-10% is located on the top of the mountain and distribute to different directions. The area density of 1-10% is an area of 2878.8 hectares.

3.2 Forest Canopy Density Changes

Map of forest canopy density changes of Mount Kelud after eruption in 2014 contain an information about the canopy density change for each pixels. The it used to calculate a quantity of a changing pixels
(reduced, stable, or increased). The decreasing canopy density forest is 8833.95 hectares, while the stable canopy density is 2149.38 ha, and increased forests canopy density is 1643.31Ha.

Canopy density changes on a map shown with a contrasting color for an interactive information display. Decreasing canopy density displayed in red, stable canopy density displayed in yellow, and increased canopy density displayed in green. Based on Canopy Density Changes Map, the most dominating is a reduced canopy density (red). Eruption caused a largely decreased of Kelud forest canopy density, the decrease was spread both in Kediri, Malang, Blitar. Stable canopy density and increased canopy density were also seen spread, but with a much narrower area than the reduced canopy density.

![Forest Canopy Density Changes of Mount Kelud before and after the eruption.](image)

**Figure 4.2** Forest Canopy Density Changes of Mount Kelud before and after the eruption.

### 3.3 Priority class of Forest Reclamation

Slope classification obtained by processing GDEM ASTER data into a degree of slope. Slope classified to 5 type: class 1 (flat), class 2 (sloping), class 3 (somewhat steep), class 4 (steep) and class 5 (very steep) with shades of brown. Increasingly steep slope then shown with a darker color.
Scene S08E112 has a range of 0 to 85.36 degrees, while scene S09E112 has a range from 0 to 77.7 degrees.

Soil fertility is determined by observing the current condition field measurement of pH, color and soil friability. The results of field measurements show that the area of forest under 1300 meters above sea level has fertile soil, while the area above 1300 meters above sea level has a less fertile soil. It was concluded that the soil is less fertile because it is affected by the eruption and has not recovered. This is confirmed by the absence of vegetation at sample plots with less fertile soil (Figure 4.4)

![Figure 4.3 Slope classification of Mount Kelud.](image)

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**Figure 4.4** Bare land area with less fertile soil at 1305 m above sea level. Location: Ngancar, Kediri  Coordinates: x = 642624.57  y = 9122875.39

Vegetation type based on field observations divided by altitude. The type of vegetation in sample plots at an altitude of 525-586 meters dominated by agroforestry crops. There are four sample plots at
an altitude of 605-692 m, two of them were dominated by grasses and shrubs and the other two are dominated by agroforestry crop. The type of vegetation in sample plots with an altitude of 873-972 m also dominated by grasses and shrubs.

Sample plots were located at an altitude above 1000 m is largely dominated by shrubs and red calliandra also there were dead trees. Sample plots that have no vegetation except for a bit of grass is a plot at an altitude above 1300 m or closest to the crater of Mount Kelud. This is likely due to the result of the eruption that occurred in 2014, and the region has not recovered so there is no vegetation.

Percentage of FCD results are used to test the accuracy. FCD before the eruption (in 2013) compared with the canopy density visual interpretation through Google Earth's imagery, while the FCD modeling results after the eruption (2015) compared with the field measurements. The analysis used to test the accuracy is the standard error of estimation and confidence level by looking at the standard deviation from the predicted data and the actual data. Based on calculation accuracy test, a score of accuracy for FCD in 2013 amounted to 83.73%. While FCD 2015 has an accuracy of 81.14%.

Forest reclamation priority class is divided into class 1a, 1b, 1c, 1d, 1e, 2a, 2b, 3a, and 3b. The results showed a lack of class priority 1c, it indicates that the research area is not encountered an area of damaged due to the impact of the eruption, but a field check on the sample plot at an altitude above 1300 m or closest to the crater of Mount Kelud. This is likely due to the result of the eruption that occurred in 2014, and the region has not recovered so there is no vegetation.

| Class of Reclamation | Condition | Area (Ha) |
|----------------------|-----------|-----------|
| 1a                   | Decreased canopy density, flat-sloping slope, fertile soil, native vegetation is decreased or disappear. | 865 |
| 1b                   | Decreased canopy density, somewhat steep-steep slope, fertile soil, native vegetation is decreased or disappear. | 2085 |
| 1d                   | Decreased canopy density, somewhat steep-steep slope, less fertile soil, native vegetation is decreased or disappear. | 413 |
| 1e                   | Decreased canopy density and native vegetation is stable or increased | 5454 |
| 2a                   | Stable canopy density and native vegetation is decreased or disappear | 1900 |
| 2b                   | Stable canopy density and native vegetation is stable or increased | 243 |
| 3a                   | Increased canopy density and native vegetation decreased or disappear | 467 |
| 3b                   | Increased canopy density and native vegetation is stable or increased | 1172 |

Based on measurements and field work, the area that goes on class 1a and 1b lies at an altitude of more than >900m. Altitude> 900 m is dominated by red calliandra (Calliandra calothyrsus). Calliandra can be categorized as a pioneer plant with a high life probability. Therefore, it can be concluded that original vegetation of these area are reduced or disappear.

Areas included in the class of reclamation 1d are above 1300 meters with a total area of 413 hectares. These area is dominated by sand or bare land. The most dominant priority class is 1e (Decreased canopy density and native vegetation stable or increased) with area of 5454 Ha. This may be due to the prevalent agroforestry areas or land use that combines trees with crops. Agricultural crops can be affected or even damaged due to the impact of the eruption, but a field check on the sample plot shows its already functioning back to normal. So it was concluded that in these sample plots the native vegetation is stable or increases. The types of agricultural crops which common in the sample plot of agroforestry is coffee and chili.
Figure 4.5. Red Calliandra
Location: Ngancar, Kediri Coordinat: x = 641507.98 y = 9122634.33

Reclamation class 2 has a stable percentage of canopy density, and are divided into two sub classes: 2a is the area that the native vegetation is gone and class 2b is areas of a remains or increases native vegetation. Both classes are symbolized by the color gradation of greenish yellow. Class 2a has a larger area than the class 2b. Class 2a has 1900 Ha whereas classes 2b is 243 hectares.
The last class of canopy density is class 3, which is a canopy density increased after the eruption. Reclamation class 3 divided by the original vegetation and symbolized by shades of green. Class 3a has an area of 467 hectares, is located at altitudes above 900 meters above sea level. Type of native vegetation is lost and then replaced by a red calliandra (\textit{Calliandra calothyrsus}) and \textit{Chromolaena odorata} (lower plants). While class 3b has an area of 1172 ha, located at an altitude below 900 meters above sea level and dominated by crop plants \textit{Neolamarckia cadamba}.

Priority classes is generalized to make an easier implementation in a real world. Single pixel can obstruct the implemention of reclamation in real world, so it must generalized and combined with a majority pixel around it.

Based on Priority of Reclamation at Mount Kelud Forest Map, it can be seen that the area around crater of Mount Kelud (near a boundary of Kediri, Malang, and Blitar) is classified as 2a (yellow) and 1a (red). And there is class 1d (bright red) which has a less fertile soil and there is no vegetation. Class of 2a, 2b, 3a, and 3b is distributed.

4. Conclusion
Based on the processing of Landsat 8 results canopy density changes: reduced canopy density with area of 8833.95 ha, canopy density that does not change is 2149.38 hectares and increased canopy density is 1643.31 ha. Accuracy test result of Forest Canopy Density (FCD) modeling is amounting to 83.73% for the FCD of 2013 and 81.14% for the FCD of 2015. So it was decided that the FCD model results can be used to make a priority of forest reclamation.

Reclamation priority of protected forest area of Mount Kelud is divided into nine classes in the order based on its priority level: class 1a, 1b, 1c, 1d, 1e, 2a, 2b, 3a, and 3b. However, on a protected forest area of Mount Kelud there are no class 1c. The most prioritized reclamation is class 1a with an area of 865 hectares, while the most dominating class is 1e with an area of 5454 Ha.

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