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Estimation of Carbon Stock at Landscape Level using Remote Sensing : a Case Study in Mount Papandayan

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ABSTRACT
Concern over global problems induced by rising CO_2 has prompted attention on the role of forest as carbon 'storage' because forests store a large amount of carbon in vegetation biomass and soil. This research aimed to develop a model for estimating carbon stock at landscape level based on the statistical correlation between stock carbon measured at plot level and the associated spectral characteristics. Estimation of carbon stocks in the field were conducted at twenty 0.3 ha plots located in various vegetation types (i.e. mixed forest, rasamala forest, pine forest, damar and puspa forest). Remote sensing data used to develop model was Landsat ETM acquired in June 2001. Using the stepwise multiple regression analysis, the best model obtained was **C =** 29.531 **TM57 –** 2.569 **RAT_7_B1 +** 104.607. Using this model, the estimated forest carbon stock of Mt. Papandayan in 1994 and 2001 were approximately 2,772,575 and 1,944,151 Mg C. During 1994 – 2001, deforestation occuring in Mt. Papandayan has resulted in decrease in forest carbon stocks for about 828,423 Mg C.

Keywords: *carbon stock, regression model, deforestation*

1.0 INTRODUCTION

Increasing concentration of greenhouse gases including carbon dioxide (CO_2) due to human activities has been widely suggested as the predominant cause of the climate change with its possible associated impacts on human health, food security and other environment degradation [1, 4, 10]. Concerns over global problems induced by the rise of atmospheric CO_2 level has prompted attention on the role of forest as carbon 'storage'. Forests play an important role in the global carbon cycle because they store a large amount of carbon in vegetation biomass and soil [3]. Conversion of especially high-biomass tropical forest to other land-uses like agriculture (deforestation) could lead to increased atmospheric CO_2 via biomass burning, increased soil respiration and decrease in CO_2 uptake by plants.

Tropical mountain forests in Java island play a critical role as carbon storage given the fact that most lowland tropical rainforests in this island has been converted to other uses. While the ecological role of tropical forest ecosystems in regulating hydrological cycle and harboring the life of millions of species is well known, its ecological role in carbon storage is less studied. Therefore, given the extent of deforestation happening in the mountainous region of Java island, it is important to develop an approach for quantifying the amount of carbon stored, i.e. carbon stock, at landscape level and monitoring its changes overtime. Remote sensing is a technology providing time series data on any earth's surface objects that can be used to develop such an approach. This study aimed to develop a remote sensing-based model to estimate carbon stock at landscape level in the forested area of Mount Papandayan using the data from Landsat ETM.

Study site

This study covered the forested area and a small extent of grassland in Mount Papandayan region. Mount Papandayan is an active volcano located in the southern part of West Java Province. The last major eruption occurred in 2002. Its peak is located at $07^o19'42''$S and $107^o44'00''$E with the elevation of 2,675 m asl. Administratively, it belongs to the Garut Regency (eastern part) and Bandung Regency (western part).

Almost all forested areas in Mount Papandayan has been designated as Nature Reserve in which the major type of vegetation is mixed forest. In the outskirt of the Nature Reserve there are production forests planted with pines, *Altingia exelsa* (rasamala) and *Agathis damara* (damar) as well as tea plantation.

2.0 METODOLOGY

This study can be divided into two main stages, i.e. model building and application of the model to estimate changes in carbon stock at the landscape level. In principle, the model was built based on the statistical correlation between the values of carbon stock measured at plot level and the associated spectral characteristics, i.e. digital numbers in Landsat ETM bands. Similar approach has also been done in [2, 5, 8]. The model was built using stepwise multiple regression analysis. Once the statistical model has been obtained, one can then use it to estimate carbon stock of each pixel in an image subset. In this way, estimation of carbon stock at landscape level can be easily performed. This paper will only discuss the model building briefly; the detailed construction of the model will be described in another paper currently being prepared.

2.1 Model Building

Field Measurement

The carbon stock in this study refers to the organic carbon held in the biomass of trees, shrubs, litters as well as the carbon in the soil. We measured carbon stocks in twenty 30 x 100 m^2 plots, largerly using allometric method as described in [13]. The plots were located in various vegetation types (i.e. mixed forest, rasamala forest, pine forest, damar, puspa forest and grassland). The coordinate of each plot was identified using a hand held GPS receiver Magellan. The plot's coordinate is critical information in this study as it is subsequently used for determining the corresponding spectral characteristics from the remote sensing data.

Image Processing

Pre processing data

The remote sensing data used to build the model is Landsat ETM band 1-5 and band 7 with spatial resolution of 30 x 30 m. The acquisition date of the image was 22 June 2001. The subset image covering the study area was then geometrically corrected using the landform map of BAKOSURTNAL 1:25,000 scale as the reference. All image processing used ER-Mapper 6.4 software.

Extracting spectral characteristics

In each plot in which the coordinate has been previously identified, a number of spectral characteristics from the Landsat image were extracted. These data were then used as input in statistical analysis. The spectral characteristics used in this study consist of single band data (i.e. the digital number of band 1, 2,3,4,5 and 7) as well as some vegetation indices and texture measures. We calculated 22 types of vegetation index, following [6, 8], and four texture measures, following [7, 9]. The complete formula for vegetation indices and texture measures can be seen in [13].

Statistical Analysis

The model was constructed using stepwise multiple regression in a similar fashion with [8]. The number of independent variables for starting the analysis was 32 variables consisting of 6 single band values, 22 vegetation indices and 4 texture measures. The dependent variable was carbon stock per pixel. The analysis was conducted to select a formulae (or equation) that uses few variables but having high correlation coeffiecent.

2.2 Landscape level carbon stock estimation by the model

The resulting model, i.e. an equation to estimate carbon stock at pixel level, was then applied for calculating the landscape level carbon stock in the Mount Papandayan region in 1994 and 2001. The subset of Landsat 1994 image was geometrically corrected using the map-to-map rectification with the 2001 image as the reference. In each image subset, the carbon stock of each pixel was calculated based on the equation developed during this study using **the formula editor menu** in ER Mapper.

3.0 RESULT AND DISCUSSION

3.1. Carbon stocks at plot level

The result of field measurement is presented in Table 1. We converted the unit of carbon stocks into Mg per 900 m^2, so that the area corresponds to the spatial resolution of Landsat data, i.e. 30 x 30 m. In general the carbon stock in the mixed forest was far higher than in the tree plantations and grasslands with the average of

23.49, 15,35 and 5,72 Mg/900 m2 respectively. The trend that mixed (natural forest) has higher carbon stock that tree plantations has been widely reported, see e.g. [12].

Tabel 1. Stock carbon in the plots

No.	**Plot Code**	**Land cover**	**Carbon stock ($Mg/900m^2$)**
1	GL-1		5.08
2	GL-2		6.78
3	GL-3	Grassland	5.36
4	MF-1		18.57
5	MF-2		17.38
6	MF-3		21.88
7	MF-4		25.37
8	MF-5		20.48
9	MF-6		19.44
10	MF-7		36.51
11	MF-8		32.09
12	MF-9		19.18
13	MF-10	Mixed Forest	24.06
14	Damar Forest		7.93
15	Pinus-Forest-planted in 1982		10.72
16	Pinus-Forest-planted in 1991		17.01
17	Rasamala-Forest-planted in 1960		16.05
18	Rasamala-Forest-planted- in 1955		12.29
19	Rasamala –Forest-Planted in 1956		16.64
20	Puspa-Forest	Tree plantation	26.75

3.2 The resulting model for estimating carbon stock at pixel
Using the data of Landsat ETM year 2001, the best equation for estimating carbon stock at pixel level was

C = 29.531 TM57 – 2.569 RAT_7_B1 + 104.607 .... (1)

C refers to carbon stock (Mg/900 m^2); **TM57** refers to the value of vegetation index calculated as the ratio of band 5 to band 7, whereas **RAT_7_B1** refers to the value of texture measure calculated for band 1 using 7x7 pixel windows. Note that estimation of carbon stock can be conducted using data from only three bands, i.e. band 1, 5, and 7. The correlation coefficient for this equation is 0.802.

3.3. Application of the model to estimate changes in carbon stock in Mount Papandayan region during 1994-2001.
We used the equation (1) to calculate carbon stock for image subsets covering the forested area of Mount Papandayan region in 1994 and 2001. The result showed that the magnitude of carbon stock in 1994 was around 2,772,575 Mg. However, this number decreased to around 1,944,151 Mg in 2001. Therefore the carbon stock decrease was 828.423 Mg or 30 % in seven years, which was a significant amount. The

decrease in the carbon stock was mainly due to the reduction of forested area as shown in Figure 1. In 1994, the forested area was 10,283 ha and this number decreased to 7,581 ha in 2001. The observation in the field and the result of land-use/cover changes analysis conducted by Center for Remote Sensing ITB indicates that most forested area have been converted into agricultural fields. Poverty was the main underlying cause triggering many destructive activities in this area including conversion of forests into agricultural fields, see [11] for fuller discussion. A similar result showing significant changes in landscape level carbon stock due to conversion of forests to other land-uses was reported by [14].

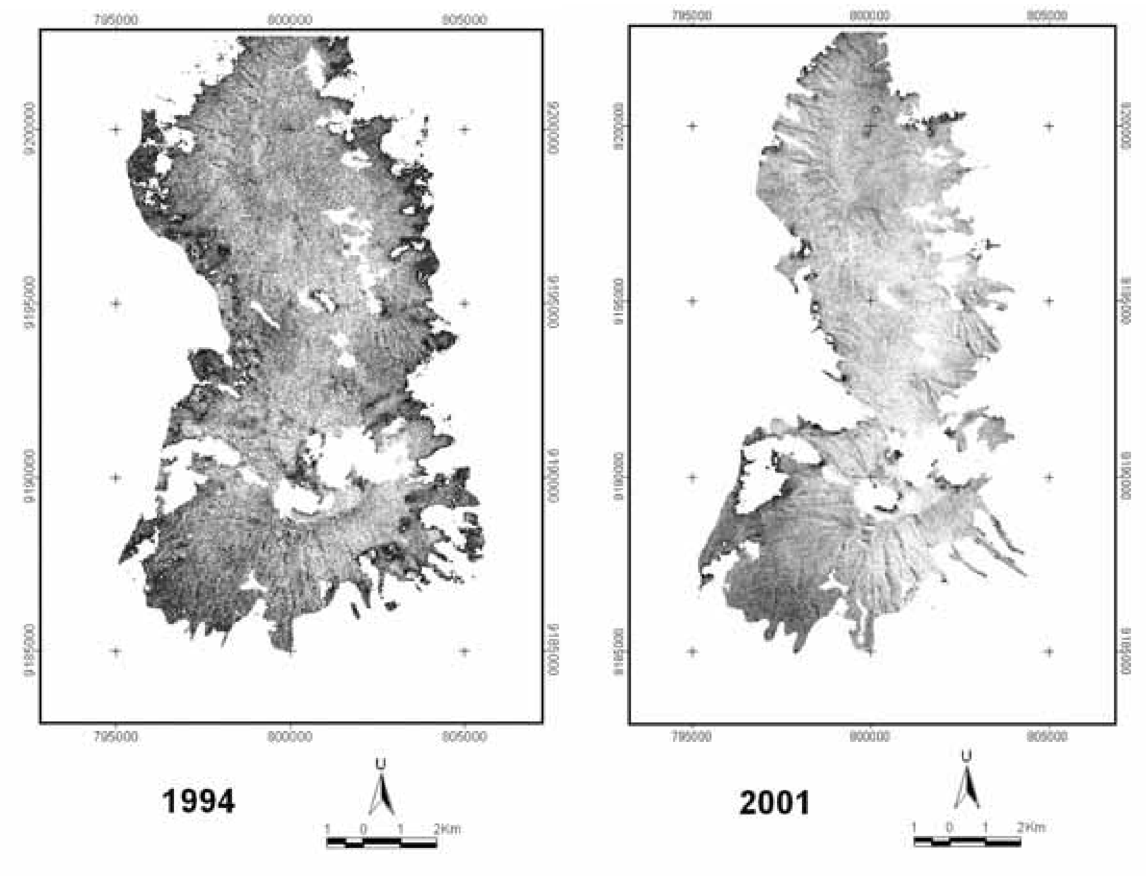

Figure 1. Changes in the forested area in the Mount Papandayan region 1994-2001

Forests play an important role in the global carbon cycle because they store a large amount of carbon in vegetation biomass and soil [3]. Therefore, deforestation as happened in the Mount Papandayan region could affect the carbon cycle in the region because it could lead to increased atmospheric CO_2 via biomass burning, increased soil respiration and decrease in CO_2 uptake by plants.

This study has shown the magnitude of deforestation and the associated impact in carbon stock reduction. Such information is important as it illustrates the extent of reforestation needed to be done in this region as well as the amount of carbon has to be accumulated during reforestation if the ecological function of Mount Papandayan forests to store carbon is to be restored.

4.0 CONCLUSION

Using the statistical model developed based on Landsat ETM data, we have demonstrated that, over the period of 1994-2001, the landscape level carbon stock in the Mount Papadayan region has decreased from 2,772,575 Mg to 1,944,151 Mg (30 % reduction) due to conversion of 2,702 ha of forested area into mainly agricultural fields. The magnitude of deforestation and carbon stock loss shows the extent of reforestation needed to be done to restore the ecological function of Mount Papandayan forest to store carbon.

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