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CHANGES IN SOIL ORGANIC CARBON RELATED TO LAND USE CHANGE DURING TWO DECADES A CASE STUDY IN THE BOGOR DISTRICT, WEST JAVA

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ABSTRACT

Soil holds an important role in the gl[21]obal C cycle as it is the largest terrestrial C pool. On the other side, the soil organic carbon dynamic is affected significantly by land use and soil management practices. It has been reported that forest conversion and cultivated activities in dynamic land use change reduce soil organic carbon. Therefore, there is an important need to assess impacts of the land use and cover changes on changes of soil organic carbon. This study is directed to the temporal assessment of Bogor district as one of the most important districts in Indonesia. The SOC was obtained from soil inventory conducted in the period of 1980 to 1990, and soil analysis conducted in 2005. Land use and cover change was analyzed using Landsat imagery recorded on June 1989 and July 2003.

The objectives of the study were to detect the land and cover changes between 1989 and 2002 by using Landsat TM and Landsat ETM+ images, and to estimate soil organic carbon and its corresponding changes associated with land use and cover changes to the last 2 decades. On the basis of temporal classification of Landsat data, there are many changes of land use during the period of 1989 to 2002. The most important is that the forest cover and paddy field decreased by about 8% and 17% of the total area respectively, while bare land / settlement and croplands increased both by about 11%. During two decades, the land use and cover changes of Bogor district reduced the total SOC by 14.7% from 235 Mt in 1989 to 201 Mt.

Keywords: land use and cover changes, soil organic carbon, soil organic matter, Bogor district

1 INTRODUCTION

At the present, a major interest of global changes research is to understand further the role of soils in carbon emissions and sequestration. Through increases in organic matter, soils have been suggested as a potentially low cost means reduce atmospheric carbon dioxide emitted by anthropogenic sources. The United Nations Framework Convention on Climate Change (FCCC) have agreed to reduce global anthropogenic emissions of carbon in order stabilize concentration of CO_2 in atmosphere at a level that will prevent disruptive changes in climate. This agreement

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requires industrialized countries to have reduce their emissions by 5–8% below 1990 levels by the period 2008–2012 [1, 2, 3]. The UNFCCC does not yet require commitments from developing countries, but recent decrease in the rates of deforestation in Asian Countries [4] may have already contributed to reduce emissions there [5].

Soil holds an important role in the global C cycle, as it is the largest terrestrial C pool. Soil can be a source (CO_2, CH_4 and N_2O) or sink (CO_2 and CH_4) of green house gases, depending on land use and management [6, 7] World soils contain about 3.2 trillion tons of carbon. An estimated 2.5 trillion tons is in the form of soil *organic* carbon. This is the organic matter in the soil that makes it fertile. The remaining 0.7 trillion tons is soil *inorganic* carbon. In fact the soil carbon pool is two or three times the entire atmospheric pool as CO_2 [8] and 2.5 to 3 times as much as that stored in plants [9, 10]. Thus, even a relatively small increase in soil carbon taken from the air could provide a significant reduction in atmospheric carbon. Moreover, since plants feed on carbon dioxide in the air, the primary way to store carbon in soil is to grow plants. Improved sustainable agriculture is the key to soil storage of carbon.

Soil organic content in soils and C flux from the soil significantly influenced by soil type, land use, and soil management practices [11, 12]. For a given soil, the greatest amount of organic matter generally accumulates in the topsoil under long-term undisturbed vegetation. It is well established that many forms of soil management can lead to changes in organic C concentrations, and the C contents of cropped and tilled soils are usually (but not always) lower than the equivalent soils under long-term grasslands or forest. The decline under more intensive forms of agriculture occur because there is increased loss of topsoil through erosion, decreased organic C return from plant residues, and enhanced breakdown of previously stabilized soil organic matter [13]. Land use and cover changes affect the amount of C stored terrestrial ecosystem. At the same time, changes in vegetation induce changes in the soil organic source. Recent analyses of land-use change have showed global terrestrial ecosystems to have been a net source of C (1.670.7 PgC yr^{-1}) during the 1980s [14]. In a comprehensive review of the effects of land-use changes on soil C stocks reported that the conversion of pasture to cropland reduces soil C stocks on average by 59% [15]. Therefore, the studying the effect of overall land use changes on distributed of SOC pools and C flux from the soils are important requirements for understanding the role of soils in the global C cycle.

The great attention of Indonesian decision makers, as well as research efforts on the study of the soil carbon cycle is not enough yet. There are no data available about the estimation of SOC, neither at national scale or at regional scale. The SOC storage in Indonesia soils had been in many small locations. The study area, Bogor district, is the district in Indonesia which is closer to the metropolitan city of Jakarta and industrial city of Bekasi. Since the last two decade the forest and the fertile agricultural areas (paddy field) have been attractive areas for new urban development. This accelerated rates of land use and cover change and urban development because of increased cultivation of land for crops and governmental changes in land use policy.

This study focused on the temporal assessment of Bogor district one of the most important districts in Indonesia. The objectives of the study was to detect the land and cover changes that have occurred between 1989 and 2002 by using Landsat TM and Landsat ETM+ images, and to estimate soil organic carbon and its corresponding changes associated with land use and cover changes in Bogor district to the last 2 decade.

2 MATERIALS AND METHODS

2.1 STUDY AREA

The study area located in Bogor District in the province of West Java, facing the metropolitan city of Jakarta in the north, District of Bekasi in the east, and its south and west boundary is District of Cianjur and Banten respectively (Figure 1). There are several reasons in the choice of this study area. The first factor is the availability of archive data of Soil Organic Carbon (SOC). In 1968, a soil survey has been done, resulting in soil map of 1: 50.000 [16]. Moreover, as the study area close to Bogor Agricultural University, the soil of Bogor was also subject of many research of undergraduate student. In the period of 1980 – 1990, there are not less than 23 undergraduate theses with complete soil analysis including SOC, realized in dispersing part of the study area [17]. The second reason is the high dynamic of land-use change of this study area.

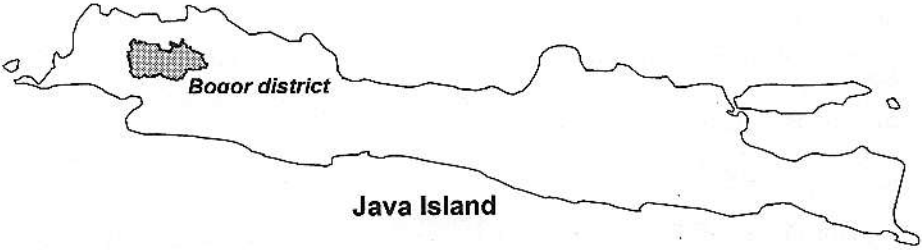

Figure 1. The study area of Bogor district

Total area of Bogor district is 316.432 Ha, which consist of 304.838 Ha of Bogor District, and 11.594 Ha of Bogor city towns. Considering this surface, Bogor District is one of the most extensive districts in Indonesia.

Monthly rainfall range between 161 to 435 mm. Areas with monthly rainfall <200 mm located in limited areas in the north-west, area with monthly rainfall between 200 to 300 mm spread over from west to east area. Here in after, areas with monthly rainfall between 300 to 400 mm located in the center and the south. Furthermore, areas with monthly rainfall >400 mm located Salak Mountain. Annual rainfall is almost in line with monthly rainfall that range from 1.926 to 5.218 mm.

Parent material consists mostly of rocks, i.e. rock of conglomerate and tuff sandstone or alluvium fan from the age of Pleistocene. The major soil order includes Ultisol, Inceptisol, Andisol and Entisol.

2.2 CALCULATION OF SOIL ORGANIC CARBON

In this study, the SOC storage consists of the SOC storage for layer 0 – 20 cm and the SOC storage for layer 20 – 40 cm. Based on LULC changes detected from multitemporary remote sensing data, changes of soil organic matter (SOM) and bulk density (BD) estimated from soil inventory and research reports and soil sampling conducted on 2004, we calculated both of SOC storage for 1980/1990 and 2004.

The SOC storage of the study area is calculated by [18, 19]:

$$SOC_i = A_i \times SOM_i \times D_i \times B_i \times 10{,}000 \times 0.58 \qquad (1)$$

where i is the LU type, SOC_i the total soil organic carbon of LU type i (t), A_i is the area of LU type i (ha), SOM_i is the average soil organic matter of LU type i (%), D_i is the soil depth (m) of LU type i, and B_i is the average soil bulk density (Mg/m3) in LU type i.

The SOM in 1980-1990 was derived from soil inventory report and undergraduate thesis report, while the SOM in 2004 was analyzed from 148 soil samples. The soil samples are representative for bare land soil of upper layer (0 – 20 cm), bare land soil of lower layer (20-40 cm), vegetative soil of upper layer (0-20 cm) and vegetative soil of lower layer (20-40 cm).

2.3 REMOTE SENSING DATA PROCESSING

The Landsat 5 TM and Landsat 7 ETM+, recorded on June 1989 and July 2002 respectively, were used to classify land use and cover in the Bogor District. The Landsat 7 ETM+ image was delivered in a geo-registered, UTM projection with 8-bit radiometric resolution to a WGS84 UTM36. Subsequently the Landsat 5 TM image was registered according to the geometry of the Landsat 7 ETM+ image. The consequent resampling was based on a nearest-neighbor algorithm, which takes the value of the pixel in the input image closest to the computed coordinate. This method is fast and does not alter the original pixel values. A first-order atmospheric correction was applied in order to account for path radiance. This correction was based on the dark pixel subtraction method.

Object oriented classification was performed to establish homogeneous areas within the images that are represented a land cover type or object class in study area, respectively. For this purpose image segmentation is carried out prior to image classification. The segmentation will subdivide an image into segments that correspond to objects based on spectral and or spatial information taken from the images. The result of the segmentation procedure is a mosaic of image objects per image layer that deliver the input data set for further classification issues. The classification of the segmented image layers is based on a fuzzy logic approach that allows complex object feature descriptions and uses membership functions (rule-sets) to conduct rules for the determination of the membership degree, i.e. the likelihood of a certain object to belong to an object class based on spectral and/or spatial attributes. Both Landsat data were segmented with a medium scale factor (scale=20). Consequently, the segmented images were classified into 5 categories.

3 RESULT AND DISCUSSION

Two Landsat Images were used to analyze the land use and cover changes in the study area of Bogor District. To detect the changes between two images, classification of each image was performed. Using the object-oriented classification the images were classified into 5 land use categories: forest, plantation, crops, paddy field and bare land/settlement. The classification results show that five land-use categories changed significantly in the study area during the 13-year period (Figure 1 and 2).

Specifically, the total area of bare land/settlement increased from 55,403 ha in 1989 to 91,851 ha in 2002, cropland increased from 70,470 ha in 1989 to 103,927 ha in 2002, and plantation increased from 28,434 ha in 1989 to 37,915 ha in 2002. In another side, forest area and paddy field area decreased by 24,975 ha and 54,406 ha in study area respectively (Table 1).

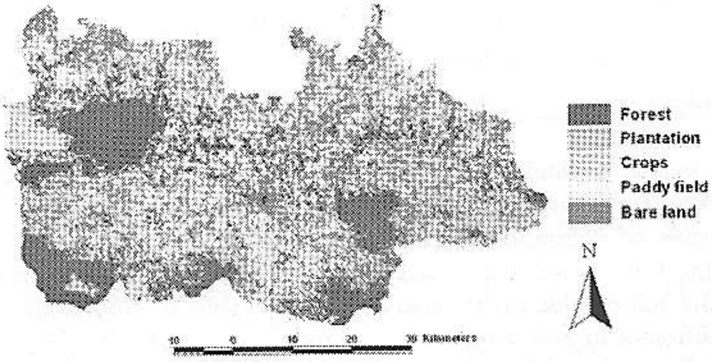

Figure 2. Distribution of land use and cover of Bogor district in 1989

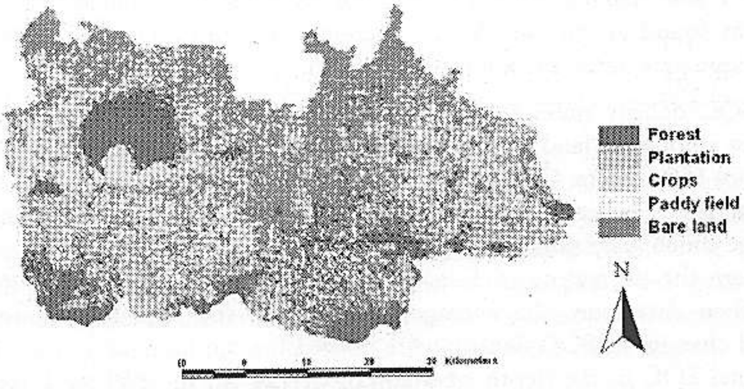

Figure 3. Distribution of land use and cover of Bogor district in 2002

From Table 1 can be seen that the total forest area and paddy field of Bogor District decreased from 25.6% to 17.7% and 25.6% to 8.4% during the 1989–2002 period, which shows a transformation from forest areas and paddy field to another land uses. Conversely, the bare land / settlement areas, crops area, and plantation area increased from 17.5% to 29.0%, 22.3% to 32.8%, and 9.0% to 12.0% respectively. Later, some parts of these paddy field which were closer to the city and networks were transformed into bare land / settlement areas where area no vegetation was clearly seen. Significant increase of crops area occurred in the upper land and the flat area of Bogor district which were closer to land use type of forest and paddy field. These changes have caused residential development and population increases in the whole Bogor district as affected by economic and urban expansion, and population increases of metropolitan city of Jakarta and Bekasi district.

Table 1. Area of land use and cover type of Bogor district in 1989 and 2002

Land Use / Cover	Land Area of 1989		Land Area of 2002		Change of Area	
	ha	%	Ha	%	ha	%
Forest	81,045	25.6	56,070	17.7	-24,975	-7.9
Plantation	28,434	9.0	37,915	12.0	9,481	3.0
Crops	70,470	22.3	103,927	32.8	33,457	10.6
Paddy Field	81,075	25.6	26,669	8.4	-54,406	-17.2
Bare land/settlement	55,403	17.5	91,851	29.0	36,448	11.5

Changes in land use and cover lead to changes of biomass and its corresponding carbon stocks. At the same time, land use and cover changes also affect the quantity and distribution of vegetation litter and soil organic inputting, which can induce changes in the soil organic matter and storage. Overall, as the vegetation cover was decreased, the soil organic matter also decreased (Table 2). Noticeably, the percent SOM was different in soil depth 0-20 cm and in soil depth 20-40 cm, where the percent SOM found in 0-20 cm was higher than found in 20-40 cm. Based on a research of soil characteristics [16, 17, 20] reported that approximately 45% of carbon was found in the top 25 cm. Therefore, the top 20 cm of the soil surface contains large part of the carbon of the horizon.

The SOC density measured on the basis of the SOM and soil bulk density differences among the land use/cover type. It decreased to the depth of 0–20 cm by 15.6% from 559 t/ha to 472 t/ha in the forest and by 11.3% from 483 t/ha to 428 t/ha in the crops, whereas SOC density in evergreen plantation and bare land did not change much. The same decreasing was arisen in SOC density to depth of 20–40 cm, here the decreasing in forest area is much more than found in 0-20 cm depth. When data from the average rates of five the land use transitions, and associated changes in SOC density were pooled for the total study area of 316,432 ha, the total SOC in the depth of 0-20 cm of 124 Mt in 1989 were estimated to decrease by 13.6.1% to 108 Mt in 2002, whereas the total SOC in the depth of 20-40 cm of 111 Mt in 1989 were estimated to decrease by 15.9% to 93 Mt in 2002. On average, land use and cover changes of Bogor district decreased the total SOC by 14.7% from 235 Mt in 1989 to 201 Mt in 2002. It indicates that in the study area occurred a small soil carbon emission during 2 decades as impact of land use and cover change. To make land use change may increase or stabilize the terrestrial carbon reserves, issues of reasonable land management and eco-environment protection should be addressed by local political and economic institutions in land use planning.

Table 2. Soil organic carbon among difference land use and cover type

Land use/	Depth	SOM (%)	BD (Mg/m	SOC storage (t/ha)	Total SOC storage (Mt)

cover	(cm)	1980-1990	2004	3)	1980-1990	2004	1980-1990	2004
Forest	0 - 20	3.71	3.13	1.3	559	472	45	26
	20 - 40	3.36	2.31	1.3	507	348	41	20
Plantation	0 - 20	3.20	2.84	1.3	483	428	14	16
	20 - 40	3.20	2.84	1.3	483	428	14	16
Crops	0 - 20	2.27	2.25	1.3	342	339	24	35
	20 - 40	2.10	1.96	1.3	317	296	22	31
Paddy Field	0 - 20	2.34	2.34	1.3	353	353	29	9
	20 - 40	1.79	1.79	1.3	270	270	22	7
Bare Land	0 - 20	1.52	1.46	1.3	229	220	13	20
	20 - 40	1.40	1.40	1.3	211	211	12	19
Sub total	0 - 20						124	108
	20 - 40						111	93
Total							235	201

4 CONCLUSION

In this study, remote sensing data has been shown as a potential technique for the study of land use changes and its corresponding soil carbon stocks. The total forest area and paddy field area decreased by 24,975 ha and 54,406 ha in study area respectively from 1989 to 2002. Changes in land use have produced severe losses in the soil carbon stocks in the study area. On average, conversion of forest and paddy field to crops and bare land / settlement in Bogor district decreased the total SOC by 14.7% from 235 Mt in 1989 to 201 Mt in 2002.

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Remote sensing data and GIS methods provide powerful instruments for the assessment and modelling of environmental indicators of the earth system and its change at multiple scales. Change, in general, is a consequence of human activities and is apparent to us in terms of climate and land cover change.

The present book addresses the up-to-date topic of change and is a compilation of scientific contributions related to mapping, monitoring and modelling "Global Change Issues in Developing and Emerging Countries". It includes the condensed results of an international biennial conference on "GIS and Remote Sensing for Environmental Studies" that took place in Göttingen, Germany from 04th to 06th October 2006.

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