Adaptation to and mitigation of climate change in the Bangsri Micro-watershed, East Java, Indonesia

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Abstract. Land use change in the Bangsri sub-catchment of the Brantas basin in East Java during the past three decades has increased both local and global climate vulnerability, by degrading soils and contributing to net greenhouse gas emissions, respectively. Our study aimed to estimate land use change and its impact on net carbon emissions, as well as to formulate strategies for adaptation to and mitigation of climate change downstream of a National park. We analyzed land cover changes from satellite imagery and measured carbon stocks in biomass, necromass and soil (0 to 30 cm) pools. Satellite imagery of land cover in 1994, 2001, 2011 and 2017 showed a decrease in natural forest area and an increase in the area of shrubs, agroforestry, production forests and annual crop land. Net CO₂ emission increased from 2.4 to 6.4 Mg ha⁻¹ year⁻¹ in the periods 2001 to 2011 and 2011 to 2017, respectively. Sand mining is the most destructive land use pattern in the area, as it leaves soil profiles stripped of their topsoil. Vulnerability to less reliable rainfall has been addressed by the common creation of small reservoirs and the abundant use of irrigation for vegetables growing under partial shade in the agroforestry zone.

1. Introduction
Climate change adaptation is aiming for reversing the trend towards increased human vulnerability, that is itself the result of land degradation, loss of diversity and climate change. Synergy with emission reduction (mitigation) is needed to address both local and global concerns simultaneously [1]. The need for a more buffered environment increases in the face of more wildly fluctuating rainfall, while the supply of hydrological buffering functions of healthy soils and biological (pest and disease) buffering of healthy ecosystems is traded off for direct gains in resource extraction and resource use (figure. 1).

Figure 1. Increased human vulnerability due to interactions between land degradation, global climate change and biodiversity loss leading to reduced buffering where increased buffering is needed
Forests provide environmental services as regulators of the hydrological cycle, maintaining biodiversity and soil productivity, as well as absorbing CO$_2$ in the atmosphere, functions that can be rapidly lost but are slow to restore [2]. In the hydrological system, forests increase the interception of rainwater through its dense canopy and understory cover, with intensively developed tree roots that are useful for increasing soil infiltration leading to surface runoff and soil erosion reduction [3], which important to adapt on climate variability. Various trees in the forest become the habitat for various fauna, starting a virtuous cycle of increasing biodiversity [4]. Related to carbon sequestration, forests are one form of land use that can absorb the largest CO$_2$ in the atmosphere compared to other land uses and store CO$_2$ as biomass and soil organic carbon (SOC) for a long time [5]. Agricultural use without adequate soil conservation practices leads to erosion and sedimentation cycles and associated loss of soil fertility and soil buffering. Loss of net primary productivity (NPP) may further lead to raising poverty levels [6]. Changes in the ecosystem, when natural forest converted to other land uses, might be temporary or irreversible resulting an invaluable loss to environmental sustainability. One of the irreversible environmental services after forest conversion is tree biomass due to changes in vegetation structure/composition. Biomass is an important factor in assessing an ecosystem, with aboveground biomass assessment required to estimate and predict ecosystem productivity, carbon stock, nutrient balance and reducing fossil fuel used [7]. The estimation of aboveground biomass in the tropics is still limited, especially the contributions of tree biomass outside forests [8].

Indonesia is inherently rich in biodiversity [9] but is rapidly losing plant and animal species due to human activity including widespread conversion of forests to agricultural land [10]. Some of the most pressing problems occur in densely populated parts of Java, where the three threats of figure 1 appear to converge. In the Bangsri micro watershed (2,985 ha), part of the Lesti Sub-watershed (Malang, East Java), recent changes in land use reflect such triple threats and call for integrated approaches to reverse current trends. Decision making in managing a such micro watershed should be in harmony with nature requires complete quantitative information on the condition of existing land cover including vegetation, biodiversity, biomass and carbon stocks that can be used as a reference in further improving policy.

Our study aimed at quantifying land use change and its impact on carbon emission and sequestration, as well as at formulating a strategy for adaptation and mitigation of climate change in the Bangsri micro-watershed.

2. Materials and methods

2.1. Study site

The study area is located in the upper area of Brantas watershed, specifically in the area of Bangsri micro-watershed (Latitude 8°5’29.1”- 8°9’7.15” S and Longitude 112°44”1.08” - 112°52’32.6” E) that is located in Malang regency, East Java province - Indonesia (figure 2).

The measurement related to vegetation and biophysics characteristics was conducted on natural forest (Bromo Tengger Semeru national park/TNBTS and production forest managed by Perhutani), agroforestry (simple and complex which are managed by farmer) and annual crops. The plot was spread from the upper to the middle zone of Bangsri micro-watershed.
2.2. Climate

Based on 10 years (2006 to 2016) monthly rainfall data in the Lesti watershed, on average of 5 months dry (<60 months) and 7 months wet (>100 mm), it is included in the ‘moderate’ class (Schmidt-Ferguson agro-climatic classification) that is summarized in figure 3. However, the number of dry months decreases in 2010 but in 2016 there are no dry months. In February 2007 an extremely wet month occurred, with an average of 666 mm month\(^{-1}\), but 3 months (July to September) was very dry. Furthermore, in 2016 there was a wet month throughout the year, with rainfall from June to September averaging >140 mm month\(^{-1}\), while rainfall from October to May averages 342 mm month\(^{-1}\). The number of rainy days also varies greatly, by 2016 there is rain throughout the year but the number of rainy days decreases from an average of 20 to 25 rain days in the rainy season to 10 rainy days in the dry season (figure 2).

Figure 3. Average rainfall per month in Bangsri micro watershed based on data of 2007 – 2016
2.3. Land use systems

The land use system in the Bangsri micro-watershed varies considerably depending on its location on the slopes, its ownership and its managers. On the upper slopes is covered by protected natural forest of TNBTS. The middle slopes, mostly are: (a) Production Forest (HP) managed by Perhutani (Indonesian state forestry company), (b) Agroforestry (AF) simple (AF-S), (c) AF multistrata (AF-M), (d) upland annual crop (chili, eggplant) are measured at the lower slope. Various land use systems (LUS) in the Bangsri micro watershed are shown in figure 4.

a. Production forest (HP) is located on the upper slopes managed by Perhutani (Indonesian State Forestry Company), tree species planted is pine (Pinus merkusii), mahogany (Swietenia mahogany), quite young suren (Toona surenii) and also 'kembang rekisi' or ‘kembang kanthil’ (Michelia alba) planted between 1950 to 1957 (approximately 60 to 67 years ago); understorey crops planted are corn and chili.

b. Multistrata agroforestry (AFM) is located in the middle of the slope is community owned land. The agroforestry classification is based on the size of the Basal Area (BA) and the number and of tree species planted. If the BA of the main tree is <80% and the tree species planted >5, then the LUS is included in the AFM. The commonly planted tree species are sengon (Paraserianthes falcataria) and mahogany (Swietenia mahagoni), but some plots have been inserted with some other tree species such as mindi (Melia azedarach), waru (Hibiscus tiliaceus), jabon (Antheocephalus cadamba), kecrutan or African tulip (Spathodea campanulata), sengon laut (Albizia chinensis), belinjo (Gnetum gnemon), petai (Parkia speciosa), salam (Syzygium polyanthum), lamboro (Leucaena leucocephala), alpukad (Persea americana), jackfruit (Artocarpus heterophyllus), coffee (Coffea sp.), gamal (Gliricidium sepium), banana (Musa parasidiaca) and papaya (Carica papaya).

c. Simple agroforestry (AFS) on the central slope is farmer-owned land managed by farmers. The land is classified AFS when BA of the main tree is <80% and the planted tree species <5. Trees species planted are generally sengon (Paraserianthes falcataria) and mahogany (Swietenia mahagoni), which are intercropped with vegetable crops (chilli and maize).

d. Crop fields (monoculture)/upland, generally on the lower slopes (Bringin village, Sanankerto, Dadapan and few in Patokpicis and Bambang villages). Plants grown are generally chili, corn, eggplant and cucumber or papaya monoculture.

e. Bamboo fields, commonly planted in riparian zones, are mostly located in the village of Patokpicis. Bamboo grown in various variety: bamboo petung, bamboo apus, bamboo java and bamboo rampal.

Figure 4. Various types of LUS selected in the middle slope for measurement of carbon stock
2.4. Net carbon emissions associated with land use change

With regard to CO₂ mitigation efforts it is necessary to quantify emissions (CO₂ release) and CO₂ sequestration throughout the Bangsri micro watershed area is done based on the stock difference approach using RaCSA (Rapid Carbon Stock Appraisal) [11,12] measurement technique. The measurement was conducted in various land uses, combined with spatial data on land cover and land use changes. Future activities are emission calculations using LUWES program [13] taking into account the actual planning of regional development. Carbon counting in 6 steps: (a) Estimation of land cover changes in the Bangsri micro watershed according to the history of land cover change by analyzing satellite images in 1994, 2001, 2011 and 2017; (b) Calculation of carbon stock factor, by calculating time-averaged C stock (total 5 pool C according to [14] of various land uses in the Bangsri sub-catchment and some data we use existing data from other activities i.e. time-averaged C stock of TNBTS, bush fallow using data in East Java [15]; (c) Extrapolation of carbon emissions per land use into the Bangsri micro watershed, by integrating the two data above to make the transition matrix of land use change; (d) Create a map of Carbon stock distribution in the Bangsri micro watershed; (e) Continue CO₂ emissions calculations using the ABACUS carbon calculation program.

2.5. Data analysis and reporting

Prior to statistical analyses, we tested all data for normality (Shapiro-Wilk’s test) and homogeneity of variance (Levene’s test) across sampling area (land use types). Logarithmic or square-root transformation was used for data that were non-normally distributed or heterogeneity of variance. We tested differences in each component for carbon stock (i.e soil carbon stock, biomass, basal area and necromass) and total carbon stock among land use types using linear mixed effects (LME) models [16]. The fixed effect was considered significant based on analysis of variance at p ≤ 0.05 and differences between sampling site or landuse were assessed using Fisher’s least significant difference test p ≤ 0.05. For a few specified parameters, we also considered marginal significance at p ≤ 0.09, because our experimental design encompassed the inherent spatial variability in our study area.

3. Results and discussion

3.1. Land use changes at Bangsri micro watershed

The method used in the land use analysis is Post Classification Comparison. The land cover change data used is derived from the land cover map of the satellite imagery classification in 1994, 2001, 2011, 2017 shown in figure 5.

![Figure 5. Land use systems in the Bangsri micro-watershed in 1994, 2001, 2011 and 2017](image-url)
By 2017, there has been a decline in the natural forest area of approximately 30% of the total area in 2011; on the other hand, there is an increase in the area of annual crop land, agroforestry, settlements and bare land. Decreasing the natural forest area will risk the decrease of C stock or in other words there is an increase of CO$_2$ emission that threatens biodiversity and crop production in the Bangsri micro watershed.

3.2. Characteristic of various land use systems

Based on the results of our survey conducted for each LUS on the middle slope (table 1) shows that natural forest has the largest trees basal area (BA) (51 m$^2$ ha$^{-1}$), while production forest (tree age is around 40 years) has BA 50 % lower than in the natural forest. Sengon (*Paraserianthes*) agroforestry has an average BA of only 12 m$^2$ ha$^{-1}$, while BA on degraded forest land is the same as BA on young mahogany land with an average BA of 4.0 m$^2$ ha$^{-1}$.

Forests have the largest BA, but the number of trees is relatively low (on average 186 trees ha$^{-1}$) than in the production forests (778 trees ha$^{-1}$) and in the agroforestry (796 trees ha$^{-1}$), this indicates that trees diameter in the natural forest is much bigger than the trees on agricultural land; while on degraded forest only contains an average of 39 trees ha$^{-1}$.

| Land use | Basal area (m$^2$ ha$^{-1}$) | Tree density (trees ha$^{-1}$) | No. tree species | Tree species encountered |
|----------|-----------------------------|-------------------------------|-----------------|------------------------|
| Taman Nasional Bromo Tengger Semeru (TNBTS) | | | | |
| Intact natural forest (INF) | 51.08 ± 7.92 d | 186 ± 28 a | 5 ± 1 c | *Acasia decurrens*, *Acmena acuminatissima*, *Camellia lanceolata*, *Casuarina junghuniana*, *Cyathea tenggerensis*, *Cyathea medullaris*, *Homolanthus giganteus*, *Irema orientalis*, *Macropanac dispermus*, *Mallotus peltalus*, *Pilea melastomoides*, *Pinanga coronata*, *Saurauia pendula*, *Wendlandia dasyothyrsa* |
| Degraded natural forest (DNF) | 3.37 ± 1.9 a | 39 ± 21 a | 2 ± 0.4 a | *Acasia decurrens*, *Calliandra haematoceph*, *Cyathea medullaris*, *Leucaena leucocephala*, *Musa paradisiaca*, *Pilea melastomoides*, *Ricinus communis*, *Vaccinium varingifolium* |
| Production forest | | | | |
| Pine + crops (HP PTs) | 25.25 ± 1.41 c | 710 ± 122 b | 2 ± 0.3 a | *Pinus merkusii*, *Zea mays*, *Capsicum annuum* |
| Monoculture pine (HP Pmo) | 28.31 ± 2.89 c | 987 ± 153 c | 2 ± 0.6 ab | *Pinus merkusii*, *Swietenia mahagoni* |
| Young mahogany (HP MMu) | 4.73 ± 0.20 ab | 742 ± 55 bc | 2 ± 0.7 ab | *Swietenia mahagoni*, *Toona sureni*, |
| Old mahogany (HP MT) | 19.79 ± 4.58 abc | 675 ± 109 b | 3 ± 0.6 abc | *Swietenia mahagoni*, *Glicididia septium*, *Syzygium polyanthum* |
| Kembang Rekisi (HP KR) | 24.52 ± 9.13bc | 133 ± 41a | 2 ± 0.3 a bc | *Michelia alba* |
| Agroforestry | | | | |
| Simple agroforestry (AFS) | 11.94 ± 0.94 abc | 826 ± 215 bc | 4 ± 0.3 bc | *Paraserianthes falcatoria*, *Swietenia mahagoni*, *Hibiscus tiliaceus*, *Carica papaya*, *Melia azedarach*, *Leucaena leucocephala*, *Anicephalus cadamba* |
| Complex agroforestry (AFM) | 12.31 ± 1.38 abc | 767 ± 119 bc | 13 ± 1.2 d | *Paraserianthes falcatoria*, *Parkia speciosa*, *Gnetum gnemon*, *Albizia chinensis*, *Persea americana*, *Melia azedarach*, *Musa parasiadiaca*, *Syzygium aromaticum*, *Glicididia septium*, *Leucaena leucocephala*, *Carica papaya*, *Swietenia mahagoni*, *Spaotedea campanulata*, *Hibiscus tiliaceus*, *Coffee sp.*, *Artocarpus heterophyllus*, *Michelia alba* |
3.3 Time-averaged C stock of various land uses
Carbon stock in each land use system consists of 5 pool C (IPCC, 2006), that are: (a) tree biomass (shoot and root), (b) understorey-- vegetable biomass (shoot and roots) (c) necromass (dead wood, branches and twigs), (d) fine litter and (e) soil organic matter (total C-organic, %). The results of the measurement of 5 pools C stock in the Bangsri micro watershed are shown in figure 6, where the largest C-stock (368 Mgs ha\(^{-1}\)) is found in the ‘Kembang Rekisi’ (HPKR) production forest aged between 60 to 67 year.

![Image of carbon stock measurements](image)

**Figure 6.** Carbon stock of each LUS measured in 24 plots in the Bangsri micro-watershed (A) and time average C stock (TAC) of each LUS (B)

The lowest C stock (51 Mg ha\(^{-1}\)) is obtained in simple Agroforestry (AFS) and monoculture (TS) annual crop. However, there is a large C-stock difference in both LUSs, AFS soils are only 13 Mg ha\(^{-1}\) whereas in the TS are about 50 Mg ha\(^{-1}\); but C-tree biomass in AFS 38 Mg ha\(^{-1}\) and in TS are only 0.9 Mg ha\(^{-1}\). The low soils C in AFS might be explained that it has been located at the sand mining area, which has lower soil fertility resulted in low biomass production and C stock.

Time-averaged C stock data of each LUS for extrapolation of C stock data at the plot to landscape level were estimated to be 205, 188, 72, 56 and 51 Mg ha\(^{-1}\) for NF, HP, AF, BS and TS, respectively, comparable with C stock data for TNBTS and average of bush fallow in East Java are obtained from earlier studies of our group [17,18].

3.4 Extrapolation of C emissions per land-use system to Bangsri micro-watershed
The integration data of the averaged -C stock with the area of each LUS is delivered in figure 7, we learned that 50% of C stock of the area is found in natural forest (TNBTS) and about 30% of C stock are present in Agroforestry and production forests; whereas the annual crop and bush hold only about 6% of the total C stock in the entire watershed.

3.5 Estimated CO\(_2\) emissions and sequestration in Bangsri micro watershed for the period 1994-2001, 2001-2011 and 2011-2017
The calculation of emission or sequestration CO\(_2\) in the Bangsri micro watershed is done by integrating activity data related to land use change ha year\(^{-1}\) and C emission factor data (Mg ha\(^{-1}\) year\(^{-1}\)). The change in C stock of each land cover change is calculated according to the stock difference method to obtain information whether the change causes emission or sequestration at two different observation times. Emissions occur when land cover changes lead to reduced carbon stocks, whereas sequestration occurs when land cover changes lead to an increase in the amount of carbon stocks. A simple calculation is performed using the following equation:
\[ \Delta C = C_A - C_B \]

Description:
\( \Delta C \) = Total change of carbon stock, Mg ha\(^{-1}\)
\( C_A \) = Total carbon stock of land cover A, Mg ha\(^{-1}\)
\( C_B \) = Total carbon cover of land cover B, Mg ha\(^{-1}\)
The full results of the calculations are shown in table 2 and figure 7.

**Figure 7.** Total contribution of each LUS to carbon stocks in Bangsri micro watersheds

**Table 2.** CO\(_2\) emissions and sequestrations in the Bangsri micro watershed related to land cover changes from 1994-2001, 2001-2011 and 2011-2017

|                | 1994-2001 (7 year) | 2001-2011 (10 year) | 2011-2017 (6 year) |
|----------------|--------------------|---------------------|--------------------|
| Area of DAS (watershed)*, ha | 2,984.04           | 2,984.04            | 2,984.04           |
| Emission, Mg    | 74,350.30          | 51,839.39           | 52,388.45          |
| Sequestration, Mg | 20,316.34       | 32,032.45           | 21,107.31          |
| Net emission, Mg | 54,033.96         | 19,806.94           | 31,281.14          |
| Rate of emission C in Mg ha\(^{-1}\) | 18.11          | 6.64                | 10.48              |
| Emission factor C in Mg ha\(^{-1}\) year\(^{-1}\) | 2.59          | 0.66                | 1.75               |
| Emission factor CO\(_2\) in Mg ha\(^{-1}\) year\(^{-1}\) | 9.49          | 2.44                | 6.41               |

Description: *Area = Area of land uses type at the watershed

In the period 1994 to 2001, the largest carbon emission occurred when compared to the other two periods, but in the next period (2001 to 2011) emission C has decreased and sequestration C increased, therefore net emission became lowest (33198 Mg). In 2001 to 2011 the amount of emissions remained the same as the previous period, but the sequestration of C was smaller; thus net C emission increases. Further calculations were made to calculate CO\(_2\) emission factor (total C x 3,567) from 3 consecutive observation periods of 9.5 Mg ha\(^{-1}\) year\(^{-1}\), 2.4 Mg ha\(^{-1}\) year\(^{-1}\) and 6.4 Mg ha\(^{-1}\) year\(^{-1}\), for the period 1994 to 2001, 2001 to 2011 and 2011 to 2017, respectively. According to the calculation of CO\(_2\) emissions in
Indonesia using the data of land cover change in 1990 to 2005, average CO$_2$ emission in Indonesia is 2.14 Mg ha$^{-1}$ year$^{-1}$ [19].

3.6. Community’s efforts to adapt to climate change

Adaptation is a community strategy in anticipating the negative impacts of climate change by taking appropriate actions to prevent or minimize the damage that may occur, or to take advantage of opportunities that may arise from climate change. In the Bangsri micro watershed, the problem is the erratic distribution of rainfall, with very wet weather in the rainy season and very dry for a long period of time in the dry season. The problem of long drought has occurred, but people who live on the upper slopes seems can cope with it, because they have a retention basin, locally known as “embung air” that can store enough water. Faced with the climate problem, many ways are done by villagers. Farmers in Perhutani’s Production Forest (upper slopes) maintaining their chili production is shown in figure 8: (a) by trimming branches and twigs to obtain sufficient light for chilies, (b) reducing evaporation by using plastic mulch, (c) applying irrigation managed by farmer group, (d) Farmers planting ‘kenikir’/marigold (Tagetes erecta) to dispel fruit fly pest that often attack the chili fruit. (e) utilization of branches and twigs of pine and bamboo forests used for firewood (mitigation of fossil fuel used).

![Figure 8. Farmers’ practices to adapt to drought problems in their region](image)

4. Conclusions

Land use change in Bangsri in the past two decades has led to lower C-stock landscapes, but increased storage of surface water and the use of irrigation pipes has allowed farmers to deal with the dry season water shortages, shifting to vegetable production under partial tree cover. Meanwhile, sand mining has increased vulnerability by leaving degraded soils behind.

Acknowledgments

This research was funded by CCCD-UNDP, the criticism and suggestions of Prof. Meine van Noordwijk (ICRAF) improving this article are highly appreciated. Also we thank to field assistance provided by Jonna Triko Mamora and farmers of Bambang village, Wajak sub-district.
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