Measuring Carbon Emissions from Deforestation at Donggala Regency, Central Sulawesi Province, Indonesia

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Abstract. Forest is a natural resource that is very important and beneficial for the livelihood either directly or indirectly. Forest has a variety of ecological functions. One of forest functions is to maintain the amount of stored carbon. The forest area changes into non-forest area resulted in reducing forest functions as a provider of environmental services. This study aims: 1) to determine the deforestation during the period of 2000-2011, 2) to make model of the landcover change using logistic regression model, 3) to measure carbon emissions and valuation based on impact of deforestation. The materials used in this study are: a) Indonesian Topographic Map at Scale 1: 50,000, Geospatial Information Agency (BIG), b) landcover map (year of 2000 and 2011), scale 1: 250,000, produced by director general of forestry planning, ministry of environment and forestry, 3) environmental variables (dependent variable) such as: distance from roads, distance from streams, elevation and slope. The spatial analysis is done by land change modeler which is module in Idrisi Terrset. Meanwhile calculations of carbon storage and economic value which are done by ecosystem service modelers also as a Idrisi Terrset. The results show that the rate of deforestation during the period of 2000-2011 at Donggala as high as 13,448.07 ha or about 1,222.55 ha per year. The impact of the forest cover changes resulted in the decrease of carbon storage up to 3.66 million tons or equivalent to 13.42 million tons of carbon emissions. Economic losses caused carbon emission in period 2000-2011 up to US$ 38,188,465 (net present value, NPV)

Keywords: NPV model, Carbon Emission, GIS, Land use Change Modeler

1. Introduction

Forest is a natural resource that is very important and beneficial for life and living either directly or indirectly. Direct benefits from the existence of the forest are timber, non-timber products and wildlife. While the indirect benefits are environmental services, such as watersheds, aesthetic function, an oxygen supplier and carbon sink.

Forest destruction, climate change and global warming reduce the indirect benefit of forest because forest is the largest carbon sink and play very important role in global carbon cycle and can hold carbon at least 10 times greater than other vegetations prairie grass, crops and tundra [1].

In 2008, the United Nations launched REDD (United Nations Collaborative Programme on Reducing Emissions from Deforestation and Forest Degradation in Developing Countries) provides a mechanism to mitigate climate change by sequestering forest carbon. REDD also promotes the secondary ecosystem service benefits associated with this forest conservation, including protection of biodiversity and water quality [2].
The average annual deforestation in Indonesia for the period 2000-2012 was 671,420 hectares, accounts for 525,516 ha of deforestation in mineral land and 145,904 ha of deforestation in peatland. During this period, 9 percent of deforestation occurred in Sulawesi Island [3]. Meanwhile, refers [4] the rate of deforestation in period 2000-2009 for Sulawesi Island was 1,667,840.59 Ha (15.58 %).

The Central Sulawesi province has forest about 4.2 million ha, so as to have a strategic role in the implementation of REDD +. The deforestation occurred in central Sulawesi Province 432,111.50 Ha (10.15 %). Donggala regency is one of regency in central sulawesi province. Meanwhile [5], in years 2000 that has forest 401.930 ha. The deforestation the period 2000-2011 was 14.790 ha (12.59 %).

Application of remote sensing and geographical information system was used to estimate land cover changes from multi temporally information. Integration from carbon factor was taken from secondary data (previous studies) and land cover changes data highly expected to give information about carbon stocks changes [6].

Managing landscapes for carbon storage and sequestration requires information about how much and where carbon is stored, how much carbon is sequestered or lost over time, and how shifts in land use affect the amount of carbon stored and sequestered over time. Valuation is applied to sequestration, not storage, because market prices relate only to carbon sequestration. Discount rates are multipliers that typically reduce the value of carbon sequestration over time [7].

How much carbon changes lost in previous studies have not been presented in spatial data (map) and based only on statistical figures, this study is based on spatial data and numbers so it will be easier to understand the form of distribution. The study aimed: 1) to determine the deforestation during the period of 2000-2011, 2) to make modeling the forest cover change using logistic regression model, 3) to measure carbon emissions and valuation base on impact of deforestation.

2. Materials and Method

Tool use in this study are ArcGis and TerrSet Software. Data Used were Indonesian Topographic Map, Scale 1: 50,000, Geospatial Information Agency (BIG); Land Use Land Cover Map of Donggala Regency, Scale 1: 250,000 (2000 and 2011), Directorate General of Forestry Planning Ministry of Environmental and Forestry (Figure 1). Included in the data are four environmental variable (dependent variable) such as distance from streams, distance from streams, elevation and slopes, Indonesian Topographic Map, Scale 1: 50,000, Geospatial Information Agency (Figure 2). Meanwhile economic data area carbon price (US$ 15) and discount rates (7 %). A table of land use cover (LULC) classes, containing data on carbon stored in each of the four fundamental pools for each LULC class. This study only calculate carbon above (carbon density in aboveground mass (Mg/Ha) (Table 1).

![Figure 1. Donggala’s Landcover](image_url)
Table 1. Emission Factor for Baplan land cover class in Central Sulawesi

| No | Land Cover                 | C Above |
|----|----------------------------|---------|
| 1  | Primary dryland forest (PF)| 195.4   |
| 2  | Secondary dryland forest (SF)| 169.7  |
| 3  | Primary mangrove forest (PMF)| 170    |
| 4  | Secondary mangrove forest (SMF)| 120   |
| 5  | Estate crop (EP)            | 63      |
| 6  | Pure dry agriculture (AUA)  | 8       |
| 7  | Mixed dry agriculture (MxUA)| 10      |
| 8  | Shrub (Sr)                  | 15      |
| 9  | Paddy Field (Rc)            | 5       |
| 10 | Fish pond/aquaculture (Po)  | 0       |
| 11 | Transmigration areas (Tr)   | 10      |
| 12 | Settlement areas (Se)       | 1       |
| 13 | Mining areas (Mn)           | 0       |
| 14 | Bare ground (Br)            | 0       |
| 15 | Open Swamp (WB)             | 0       |

Source: Refer 8

Logistic regression model (LRM) was used to model and analyze the landcover change in IDRISI TerrSet. The objective of the present study was to assess the importance of the explanatory variables on landcover change from 1990 to 2000 and predicting the probability of change by 2011. The binary presence or absence is the dependent variable for the periods 1990–2000. The predicted landcover of 2011 was validated using ROC / AUC (Relative Operating Characteristic/Area Under Curve) module of IDRISI TerrSet. The ROC module is comparing a suitability image depicting the likelihood of that class occurring (the input image) and a boolean image showing where that class actually exists (the reference image). The ROC curve is the true positive fraction vs false positive fraction and the AUC is a measure of overall performance [8].
2.1. Carbon storage/ Sequestration Model and Valuation

Calculation of emissions using the stock changes approach (stock difference) which was measured at two different time points using two factors, namely: activity data and emission factors. The main data of carbon stocks changes was derived from the data of the land cover change [6].

Carbon storage/ Sequestration model needs the map and data tables, including the economic data. Land use/land cover (LULC) map must be a raster format, with a LULC code for each cell. The dataset should be projected in meters (UTM 50 S). The year (2000, 2011 and 2022) depicted by the LULC map, for use in calculating sequestration and economic values [7].

The carbon prices observed in these instruments vary significantly, from less than US$1/tCO2e to $US130/tCO2e. Majority of emissions (85 percent) are priced at less than US$10/tCO2e (Kossoy, et.al, 2016). In this study use assumptions the social cost of carbon (SCC) US$15 per metric ton of C and market discount rate ($r = 7\% \text{ per year}$). The value of carbon sequestration over time for a given parcel $x$ is:

\[
\text{value}_{\text{seq},x} = V \frac{\text{sequest}_x}{y_{r_{\text{fut}} - y_{r_{\text{cur}}}}} + \sum_{t=0}^{y_{r_{\text{fut}}}-y_{r_{\text{cur}}}-1} \frac{1}{(1 + \frac{r}{100})^t (1 + \frac{c}{100})^t}
\]
3. Results and Discussion

3.1. Landcover Change

Landcover change analysis was done for Donggala compared time series data from 2000 until 2011. Table 2 show the changes of land cover Donggala Regency in from 1990 to 2022*.

| No | Type of Landcover          | Years 2000 | Years 2011 | Years 2022* |
|----|----------------------------|------------|------------|-------------|
|    | Ha | Percent | Ha | Percent | Ha | Percent |
| 1  | Primary Dryland Forest     | 259,717.59 | 54.52 | 206,347.59 | 43.31 | 165,387.60 | 34.72 |
| 2  | Secondary Dryland Forest   | 129,316.23 | 27.14 | 169,246.62 | 35.53 | 209,263.41 | 43.93 |
| 3  | Primary Mangrove Forest    | 562.5 | 0.12 | 506.88 | 0.11 | 506.88 | 0.11 |
| 4  | Secondary Mangrove Forest  | 300.15 | 0.06 | 347.31 | 0.07 | 347.31 | 0.07 |
| 5  | Estate Forest              | 7,704.72 | 1.62 | 7,704.72 | 1.62 | 7,704.72 | 1.62 |
| 6  | Dryland Agriculture        | 43,060.23 | 9.04 | 44,007.12 | 9.24 | 44,599.50 | 9.36 |
| 7  | Mixed Dryland              | 10,820.07 | 2.27 | 15,131.16 | 3.18 | 15,131.16 | 3.18 |
| 8  | Shrub                      | 11,324.88 | 2.38 | 18,744.57 | 3.93 | 19,095.39 | 4.01 |
| 9  | Paddy Field                | 7,905.87 | 1.66 | 8,666.82 | 1.82 | 8,666.82 | 1.82 |
| 10 | Fishpond                   | 1,336.95 | 0.28 | 1,345.41 | 0.28 | 1,345.41 | 0.28 |
| 11 | Transmigration             | 151.11 | 0.03 | 151.11 | 0.03 | 151.11 | 0.03 |
| 12 | Settlement                 | 3,721.50 | 0.78 | 3,721.95 | 0.78 | 3,721.95 | 0.78 |
| 13 | Mining Area                | 218.52 | 0.05 | 218.52 | 0.05 | 218.52 | 0.05 |
| 14 | Bare Ground                | 216.72 | 0.05 | 216.72 | 0.05 | 216.72 | 0.05 |
| 15 | Open Swamp                 | 47.79 | 0.01 | 47.79 | 0.01 | 47.79 | 0.01 |
|    | Sub Total Non Forest       | 86,508.36 | 18.16 | 99,955.8 | 20.98 | 100,899.09 | 21.18 |
|    | Total                      | 476,404.83 | 100 | 476,404.83 | 100 | 476,404.83 | 100 |

Source: Result of Analysis of Landcover Map in year 2000, 2011 and 2022* (Projected)

The forest cover area in Donggala in 2011 was 376,448.40 ha or approximately 79.02% of the total area. It has been decreased by 13,448.07 ha (16.15%) compared to 2000. The forest degradation was 40,960 ha or 4.096 ha year\(^{-1}\).

Primary dryland forest conditions in Donggala Regency in 2000 covered 259,717 ha and in 2011 reduced into 206,347.59 ha. A reduction was 53,370.00 ha or approximately 20.553 % over the 11 years. The average deforestation of primary dryland forest occurred in Donggala was 1.86% per year or about 4,851.82 ha per year. The reduction was caused by deforestation which has changed primary dryland forest into a secondary dryland forest. The reduction of primary dryland forest caused an additional extensive secondary dry forest directly, because deforestation in Indonesia is the selective cutting of trees which had 50 emand up diameter of the trees.

In 2000 the secondary dry forest area in Donggala was 129,616.38 ha and in 2011 decreased to 169,593.93 ha. The replenishment of secondary dryland forest area was 39,977.55 ha, or approximately 46.59% over the 11 years. The increasing average of secondary dryland forest was 4.23% per year, or about 3,634.32 ha per year. The replenishment of secondary dryland forest was caused by the degradation, which has changed the primary dryland forest into secondary dryland forest. Tabel 3 shows leucover changes (increasing and decreasing).
Table 3. Landcover changes of Donggala Regency period 2000-2011 and 2011-2022*

| No | Type of Landcover       | 2000-2011     |        | 2011-2022*     |        |
|----|-------------------------|---------------|--------|----------------|--------|
|    |                         | Ha            | Percent| Ha             | Percent|
| 1  | Primary Dryland Forest  | -53,370.00    | -20.55 | -40,959.99     | -19.85 |
| 2  | Secondary Dryland Forest| 39,930.39     | -30.88 | 40,016.79      | 23.64  |
| 3  | Primary Mangrove Forest | -55.62        | -9.89  | 0.00           | 0.00   |
| 4  | Secondary Mangrove Forest| 47.16         | 15.71  | 0.00           | 0.00   |
|    | Total Forest            | -13,448.07    | 16.15  | -943.20        | 3.79   |
| 5  | Estate Forest           |               |        |                |        |
| 6  | Dryland Agriculture     | 0.00          | 0.00   | 0.00           | 0.00   |
| 7  | Mixed Dryland Agriculture| 946.89       | 2.20   | 592.38         | 1.35   |
| 8  | Shrub                   | 4,311.09      | 39.84  | 0.00           | 0.00   |
| 9  | Paddy Field             | 7,419.69      | 65.52  | 350.82         | 1.87   |
| 10 | Fishpond                | 760.95        | 9.63   | 0.00           | 0.00   |
| 11 | Transmigration          | 8.46          | 0.63   | 0.00           | 0.00   |
| 12 | Settlement              | 0.00          | 0.00   | 0.00           | 0.00   |
| 13 | Mining Area             | 0.45          | 0.01   | 0.00           | 0.00   |
| 14 | Bare Ground             | 0.00          | 0.00   | 0.00           | 0.00   |
| 15 | Open Swamp              | 0.00          | 0.00   | 0.00           | 0.00   |

Total Non Forest: 13,447.53 15.54 943.20 0.94

Over the 11 years (2000-2011) the increase of non-forest area was 13,448.07 ha or 15.54% compared to the condition of the forest cover in 2000. The rate of change was 1,222.50 ha per year or the reduction was 1.41% per year compared to non-forest areas condition in 2000. The increase of non-forest areas was caused by the activity of forest land conversion into non-forest areas (other uses). The next figure 4 shows the trend of forest changes in Donggala regency.

Figure 4. Forest Changes from 2000 to 2022

Referring to the above graph can be explained the primary dry forest decline is inversely proportional to the rise in the number of secondary dry forest that reaches 15% between 2012 and 2022. Donggala District is one of district in Central Sulawesi Province, which contribution of 12.59% total deforestation in Central Sulawesi Province in period 2000-2011 [5]. The forest cover in Donggala district in 2011 was 387,140 ha or approximately 81.26% of the total area. It has been decreased by 14,790 ha (3.68%) compared to 2000. The rate of deforestation in period 2000-2011 is 344.55 ha year⁻¹. Motivated by Sumargo et al. [4] the rate of deforestation in Donggala district is lower than deforestation in central sulawesi 43,211,15 ha year⁻¹.

The changes of forest cover was caused by the deforestation, either planned or not. Planned deforestation is usually in the form of changes planned by the government for the benefit of forest land for plantations, agricultural or residential development, which is carried out lawfully in accordance with the legislation. Unplanned deforestation is a deforestation through illegal activities. The forest degradation can be caused by illegal or unauthorized activities, such as harvesting and illegal logging.
3.2. Carbon storage/Sequestration model and valuation

The output from model simulation is raster maps, produced by carbon storage and sequestration module are 1) Map of current carbon storage, Map of future carbon storage, Carbon sequestration map, Map of economic value of carbon (Figure 5) and 2) a summary of storage and sequestration and net present values of sequestration (Table 4).

![Figure 5](image)

**Figure 5.** Map representing Carbon storage and Carbon sequestration in period 2000-2011

| No | Parameter                                   | Period 2000-2011 | Period 2011-2022* |
|----|---------------------------------------------|------------------|-------------------|
| 1  | Total current carbon (Mg)                   | 73,978,140       | 70,487,819        |
| 2  | Total value of currently stored carbon (US $) | 110,967,2117     | 10,57,317,306     |
| 3  | Total scenario carbon (Mg)                  | 70,487,819       | 69,285,088        |
| 4  | Total sequestered carbon (Mg)               | -3,490,321       | -1,202,732        |
| 5  | Total value of sequestered carbon (US $)    | -38,188,465      | -13,159,386       |

Total current carbon (year 2000) is 73.980 Mton. Meanwhile in the future, total carbon (year 2011) is 70.49 million ton. Hence, total sequestered is -3.49 million on. Negative values indicate carbon lost to the atmosphere. Areas with large negative e values will have the largest changes in land cover. In the study, Donggala has been decreased by 13,448.07 ha (16.15%) compared to 2000. The forest degradation was 40.960 ha or 4.096 ha year⁻¹.

By measuring the amount of C storage in the bodies of living plants (biomass) in the landscape, can calculate the amount of CO₂ in the atmosphere is absorbed by plants. Donggala area almost as large an area with carbon strotage content more than 15 up Mg per cell (166,67 Mg per ha).

The impact of land cover changes caused decreased carbon stocks, especially in the forest area. In 2000 the forest area is 389,896 ha, equivalent to the carbon storage of 72.83 million ton. In 2011, decline in forest area of by 13.448 ha, resulted in a decrease of carbon 3.66 million tons.
The reduction of CO$_2$ in the air by the plants was called seprocess (C sequestration). This C sequestration process occurs for the survival of plants which need sunlight, carbon dioxide gas (CO$_2$) is absorbed from the air and water as well as nutrients absorbed from the soil. Through the photosynthesis process, the CO$_2$ in the air is absorbed by plants and converted into carbohydrates, afterwards they are distributed throughout the body of the plants and eventually are dumped throughout the plant body. Thus, measuring the amount of C stored in the body of living plants (biomass) in a field can describe the amount of CO$_2$ in the atmosphere absorbed by plants [9].

The map of the Net Present Value (NPV), is the economic value of total sequestration in Donggala Regency area. It could be observed from 2000 to 2011 (and 2011 to 2022 *) there was a value of US$ -187.48 to 25.269 per metric ton per pixel in areas. Meanwhile in period 2011-2022 * there was a value of US$ 0 to -177.66. The output map are the changes in land cover and its effects in sequestration. It is possible to see that the raster has a large variety of classes and that more areas are close to becoming emitters while others have already made the transition [10].

Base on Table 4, the Net Present Value (NPV) over time of total sequestration (between the current and the future) in Donggala Regency is US$ 38.19 million caused by the carbon emissions, base on price of carbon is US$ 15 and discount market is 7%. Negative values indicate carbon lost to the atmosphere (emissions of CO$_2$). Costs required to restore the initial conditions, so that the forest come back to normal and can absorb CO$_2$.

**Figure 6.** Map representing Carbon storage and Carbon sequestration in period 2011-2022
4. Conclusion

The forest cover area in Donggala in 2011 was 376,448.40 ha or approximately 79.02 % of the total area. It has been decreased by 13,448.07 ha (16.15 %) compared to 2000. The forest degradation was 40,960 ha or 4.096 ha year\(^{-1}\). Total of carbon storage (only carbon above) throughout the land cover in Donggala Regency in 2011 reached 3.49 million tons C. The carbon storage had been decreased by 317,301.91 ton C or the average was 317,301.91 tons C year\(^{-1}\) compared to the carbon storage in 2000.

The impact of land cover changes caused decreased carbon stocks, especially in the forest area. In 2000, forest area is 389,896 ha, equivalent to the carbon storage of 72.83 million ton. In 2011, decline in forest area of by 13.448 ha, resulted in a decrease of carbon 3.66 million tons. The net present values of sequestration (between the current and the future) US$ -38.19 million caused by the carbon emissions, based on price of carbon is US$ 15 and discount market is 7 %.

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