# Estimation of Carbon Release from Tropical Deforestation Using High-resolution Satellite Data

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**Abstract – Recent global climate change is the consequence of many human activities; deforestation in the tropics is one of them. The research estimated the amount of carbon flux due to forest cover change by combining satellite image information and terrestrial field-based inventory. The study area is located at a tropical forest region of southeastern Bangladesh. It used Landsat TM and ETM+ satellite images and terrestrial sample based inventory data. The result is quite useful to understand the terrestrial carbon dynamics and global climate change.**

**Keywords:** Biomass, Carbon release, Carbon sequestration, Landsat, Deforestation

## 1. INTRODUCTION

Global climate change is the consequence of many human activities; accumulation of atmospheric carbon is one of them. Prior to the nineteenth century humans exerted only a modest influence on terrestrial carbon storage through fire, fuel use and deforestation, but since the outset of the industrial revolution, human activities have had a major effect on the global carbon cycle. Between 1850 and 1980, more than 100 Gt of carbon were released into the atmosphere as a result of land use changes, representing about one-third of the total anthropogenic carbon emission over this period (Houghton 1996).

Until the late nineteenth century most forest clearing and degradation took place in temperate regions. In the twentieth century, the area of temperate forest largely stabilized and tropical forest became the primary source of carbon emissions from terrestrial ecosystems (Houghton 1996).

In recent decades, many temperate forest regions (such as Europe and eastern North America) have become moderate carbon sinks through the establishment of plantations, the re-growth of forests on abandoned agricultural lands, and increased growing stock in forests. In contrast tropical forests have become a major source of carbon emissions; the rate of tropical deforestation is estimated to have been 15.5 million per year in the period 1980-1995 (FAO 1999).

Therefore, carbon accounting, especially in the tropical forest region is important. The aim of the current study is to apply a suitable method using remote sensing and terrestrial samples to estimate the amount of carbon emission due to tropical deforestation from a selected test site.

## 2. MATERIALS AND METHODS

### 2.1 Description of Study Area and Forest

The test site is located at the southern Chittagong, Bangladesh. It covers 21°29´to 21°37´ N Latitude and 92°05´ to 92°13´ E longitude. The area enjoys a sub-tropical monsoon climate. Monsoon starts in July and stays up to October. The period accounts for 80% of the total rainfall.

The forest of the study area is classified as tropical wet evergreen and semi-evergreen forest (Champion *et al.* 1965). The outstanding feature of the forest vegetation is the frequent occurrence of the general Dipterocarpus, Quercus and Eugenia (*Syzygium* spp) (Baten 1969). As all the accessible areas were transformed to shifting cultivation, virgin forests can be seldom noticed.

### 2.2 Satellite Image Analysis and Field Sampling

Landsat ETM+ and TM data were used in this study. The study period deals with the last decade, starting from 1992 to 2001. Relative atmospheric correction was done by image-based COST method (Chavez 1996). Images were geo-coded from a reference image, which is previously rectified from the topographic maps of Survey General of Bangladesh.

Ground survey was conducted to measure the trees of temporary sample plots. *Dbh* (diameter at breast height) and height of all the plants inside the sample plots were measured and then converted to biomass and carbon contents using allometric relations and form factors.

## 3. RESULTS

### 3.1 Estimation of Carbon Pool

The carbon pool was estimated using a combined method of regression and stratification. Stratification from supervised classification based on forest types provided the optimal result. Information from stratification in the form of dummy variables was added in regression. Each vegetation class was considered as a source of different sets of dummy variables. Details of those analyses are presented by Rahman (2004). The selected regression equation becomes:

$$C = \exp^{(6{,}19 - 36{,}534 * \text{ref b2} - 0{,}462 * Z1 - 0{,}582 * Z2 - 0{,}226 * Z3 + 0{,}945 * Z4 + 3{,}098 * Z5 - 3{,}75 * Z6)} \quad (r^2 = 0{,}887)$$

Where, C is carbon in ton per ha, exp is the base of natural logarithm, refb2 is the reflectance of band 2 in decimal. ‘Z’s are the coefficients of dummy variables based on forest type classification. The details of ‘Z’s are presented in table 1.

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Table 1. The co-efficient of dummy variables

| Forest types | Z1 | Z2 | Z3 | Z4 | Z5 | Z6 |
|---|---|---|---|---|---|---|
| Acacia | 1 | 1 | 1 | 1 | 1 | 1 |
| Bamboo | 0 | 1 | 1 | 1 | 1 | 1 |
| Plantation of indigenous spp. | 0 | 0 | 1 | 1 | 1 | 1 |
| Primary forest | 0 | 0 | 0 | 1 | 1 | 1 |
| Rubber | 0 | 0 | 0 | 0 | 1 | 1 |
| Shrubs | 0 | 0 | 0 | 0 | 0 | 1 |
| Teak | 0 | 0 | 0 | 0 | 0 | 0 |
| Secondary forest | 0 | 0 | 0 | 0 | 0 | 0 |

### 3.2 Assessment of Forest Cover Change

Forest cover change is quantified and presented by vegetation change matrix showing the dynamics of vegetation change during the study period (Table 2). Primary and secondary forests are subject to a severe loss; reduction of primary and secondary forest is about 35% and 56% respectively. The destruction of teak (scattered trees are also misclassified to this category) and indigenous plantation was relatively lower. They have lost only about 15% and 17%. Acacia has been recently introduced to the study area and was not available in 1992 image. Rubber plantation is extended dramatically (about 56%). The bamboo areas have also slightly been increased, which is about 5%. The shrub vegetation has been tremendously expanded and it is about 80%. Non-forest area has also been increased (about 19%).

### 3.3 Assessment of Carbon Flux

The quantification of carbon flux is summarized and presented in table 3. The study found that a major amount of carbon was released due to the conversion of primary forests. It also estimates that around ten ton of carbon per ha was released due to the degradation of that forest. Some of the other classes, i.e. indigenous plantation and shrub have released a negligible amount of carbon. Most of the other classes exhibit forest growth and carbon sequestration. The highest amount of carbon is sequestrated by acacia and it is about 25 ton per ha in nine years, i.e. 2,78 ton per ha per annum. The amount of carbon sequestrated by bamboo and secondary forest was satisfactory and it was 18 and 15 ton per ha respectively.

The study shows that the carbon release hotspots are distributed scatterdly and concentrated in some regions (figure 1). Many of those hotspots are located at the frontier zone of the forest and non-forest regions. Sometimes the hotspot is isolated and a complete devastation is noticed. In contrast, carbon sequestration hotspots are much smaller in size (figure 2). Many of these hotspots are the consequence of plantation activity.

## 4. DISCUSSIONS AND CONCLUSION

The carbon pool of a tropical forest ecosystem varies with many factors, i.e., the types and stocking of forest, site quality, disturbing patterns etc. Accurate results can only be obtained from the local level studies. Uncertainties increase when it estimates on a regional or global level, unless a sound sampling system is applied to get the information from all the representative forest and stocking conditions.

Table 2. Vegetation Change Matrix 1992-2001 (area in ha)

| Landsat 136/045 | Year: 2001 | Natural forest vegetation | | Plantation | | | | Non-forest vegetation | | Non-vegetated | Total 1992 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year: 1992 | | Primary forest | Secondary forest | Indigenous spp. | Teak | Acacia | Rubber | Bamboo | Shrubs | | |
| Natural vegetation | Primary forest | 2 687 | 273 | 248 | 1 344 | 53 | 346 | 613 | 132 | 371 | 6 067 |
| | Secondary forest | 444 | 340 | 240 | 271 | 16 | 281 | 513 | 119 | 125 | 2 349 |
| Plantation | Indigenous spp. | 200 | 136 | 958 | 325 | 160 | 262 | 62 | 525 | 372 | 3 000 |
| | Teak | 339 | 41 | 150 | 1 100 | 7 | 595 | 240 | 259 | 1 779 | 4 510 |
| | Acacia | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Rubber | 45 | 27 | 225 | 163 | 21 | 471 | 57 | 395 | 521 | 1 925 |
| Non-forest vegetation | Bamboo | 148 | 179 | 198 | 176 | 2 | 457 | 1 045 | 110 | 119 | 2 434 |
| | Shrubs | 17 | 26 | 346 | 55 | 28 | 218 | 22 | 649 | 314 | 1 675 |
| Non-vegetated | | 70 | 12 | 189 | 312 | 54 | 376 | 14 | 834 | 7 434 | 9 295 |
| Total 2001 | | 3 950 | 1 034 | 2 554 | 3 746 | 341 | 3 006 | 2 566 | 3 023 | 11 035 | 31 255 |

Table 3. Estimates of carbon flux

| Forest type | 1992 | | | 2001 | | | Change in mean Carbon (ton/ha) | Change in total carbon (ton) |
|---|---|---|---|---|---|---|---|---|
| | Area (ha) | Carbon (ton/ha) | Total carbon (ton) | Area (ha) | Carbon (ton/ha) | Total carbon (ton) | | |
| Primary forest | 6 067 | 143,60 | 871 224 | 3 950 | 133,18 | 526 077 | -10,42 | -345 147 |
| Secondary forest | 2 349 | 86,37 | 202 883 | 1 034 | 101,40 | 104 849 | 15.03 | -98 034 |
| Plantation of ind.spp. | 3 000 | 61,96 | 185 867 | 2 554 | 61,77 | 157 766 | -0.19 | -28 101 |
| Teak | 4 510 | 69,99 | 315 646 | 3 746 | 73,69 | 276 050 | 3,70 | -39 596 |
| Acacia | 0 | | | 341 | 25,27 | 8 617 | 25,27 | 8 617 |
| Rubber | 1 925 | 23,24 | 44 739 | 3 006 | 31,14 | 93 594 | 7,90 | 48 855 |
| Bamboo | 2 434 | 47,36 | 115 270 | 2 566 | 65,25 | 167 434 | 17.89 | 52 164 |
| Shrubs | 1 675 | 0,97 | 1 627 | 3 023 | 0,86 | 2 614 | -0.11 | 978 |
| Non- forest | 9 295 | | | 11 035 | | | | |
| Total | 31 255 | 55,58 | 1 737 256 | 31 255 | 42,78 | 1 337 000 | -12,80 | -400 256 |

The positive value in the last two columns indicates sequestration and the negative value indicates release

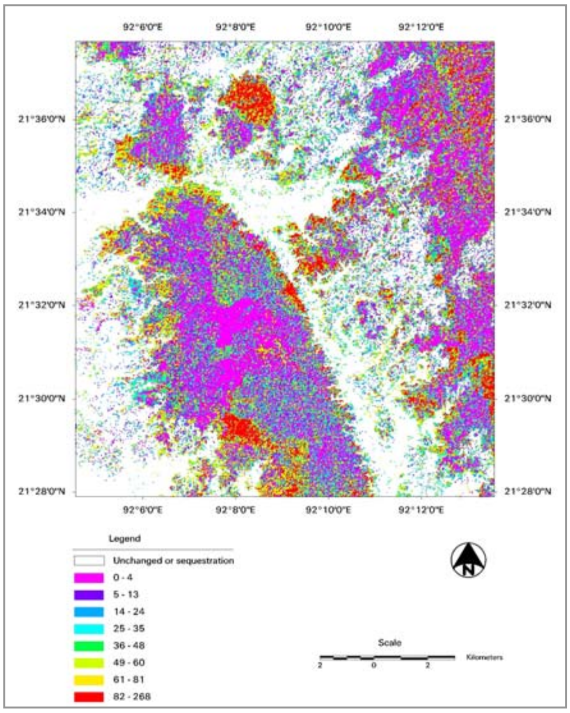


Figure 1. Carbon release map 1992-2001 (area in ha)

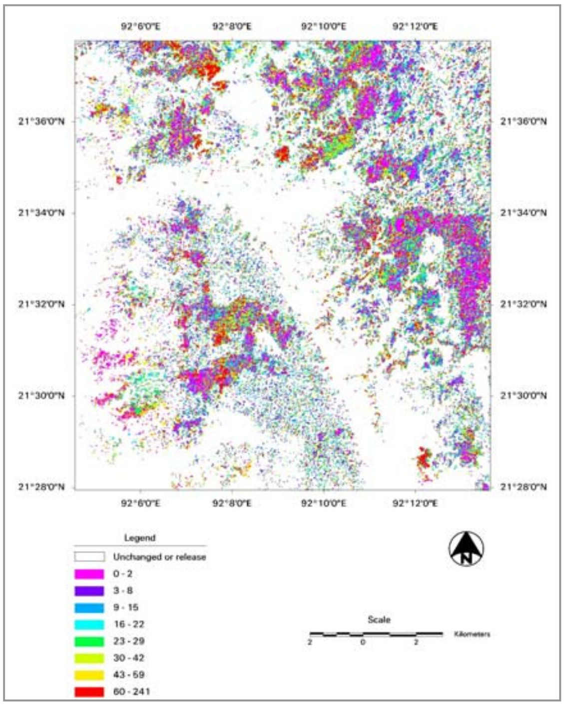


Figure 2. Carbon sequestration map 1992-2001 (area in ha)

The current study is a local-level study. This research estimated that the mature tropical evergreen and semi-evergreen forest of the study area contains the highest amount of carbon among the all classes. It is approximately 133 ton/ha. The result is quite close to the estimate mentioned by Dixon *et al.* (1994). That study reported that the tropical forest in Asia holds a carbon density of 132-174 ton/ha in vegetation. Brown and Lugo (1984) estimated that the tropical forests of Bangladesh hold approximately 55-90 ton/ha of carbon in biomass.

Secondary forest holds much lower amount of carbon. The current study estimated that the secondary forest holds 100 ton/ha of carbon (75% of the primary forest). Secondary forest of Rodontia, Brazil, contains about 40-60% of biomass of the primary forest biomass (58 to 149 t/ha of C) after 18 years of abandonment (Alves *et al.* 1997). The clearing history of the secondary forest of the current study area is unknown. The area was allotted for felling in different coupes; the practice was stopped officially during late 1980s to stop the further degradation of forest in the country.

Plantation holds a relative lower carbon content than the primary and secondary forests. However, the amount of carbon sequestration by a plantation forest depends upon the species planted and its growth rate, site quality, cultural and tending operation, disturbance etc. Indigenous and teak plantations in the study area were estimated to have 60-75 ton/ha carbon. The class rubber contains about 30 ton/ha of carbon. Short rotation acacia has a relative lower amount of carbon (25 ton/ha).

Scrub vegetation has less than 1 ton/ha of carbon. This ecological zone is very close to the habitation. Most of the forest in the study area belongs to the Government property. The control system to protect forest of this region has broken down. The area seems to be under the process of repeated disturbance by human interference, which hinders the process of succession to form secondary forest.

About 4 00 250 ton of carbon was released during 1992-2001 (nine years) from our investigated test site. It means that about 44 473 ton/year (1 ton = 106 gram) was released from 31 255 ha (about 313 sq. km) of the study area. Dixon *et al.* (1994) reported that the annual C flux from tropical Asian forest is –0.50 to –0.90 Pg/year (I Pg = 1015 gram). The ratio of the C flux of the study area to that figure of continental scale is quite small (0.9 x $10^{-4}$ to 0.5 x $10^{-4}$). The test site has released around 13 ton/ha of carbon in 9 years, i.e. 1,4 ton/ha/year from the ecosystem.

Harmon *et al.* (1996) reported that during harvest approximately 50% of the living biomass is converted to additional woody debris that decay on site. Approximately 40% of the carbon removed from the site and distributed to the forest products sector quickly returns to the atmosphere due to losses during primary and secondary manufacturing as well as to incineration and decomposition of short-lived forest products. They stated that the remaining forest products decompose slowly, at a rate of approximately 2% per year. This means that about 2 00 130 ton i.e. 0.71 ton/ha carbon (2.61 ton $CO_2$) was released to the atmosphere from our test site or is going to be released soon during the harvesting process. Another 80 050 ton of carbon (2 93 790 ton of $CO_2$) has already been released or is going to be released shortly during the secondary manufacturing.

However, all the carbon removed from the ecosystem does not come back to the atmosphere immediately. The fate of carbon depends upon the end-use of forest products. Local level study about the durability of different forest products of that region is quite absent. Further studies can be carried out to explore the duration of carbon locked in dead-pool and facilitate accurate estimate of $CO_2$ emission due to deforestation.

## 5. ACKNOWLEDGEMENTS

The first author is grateful to 'Gottlieb Daimler und Karl Benz Stiftung' for granting scholarship. The authors would like to thank to the Gesellschaft von Freunden und Förderern of Dresden University of Technology and Studienbegleitprogramm (STUBE) Sachsen for their partial financial support. The contributions of Barbara Koch, Department of Remote Sensing and Landsacpe Information System, Albert-Ludwigs University, Freiburg and Michael Koehl, Department of World Forestry, University of Hamburg are acknowledged for their comments and suggestions during the study.

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