Integration of tree cover and land cover data for estimation of greenhouse gas emissions and removals for REDD+ in Bangladesh

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In Bangladesh, historical emissions and removals of anthropogenic greenhouse gases associated with deforestation, forest degradation and enhancement of forest carbon stocks were measured for the reference period 2000-2015. The 2006 Guidelines of the Intergovernmental Panel on Climate Change were applied to develop the national forest reference level (FRL) with the objective to assess the country's performance in implementing REDD+ activities under the United Nations Framework Convention on Climate Change. For the assessment of historical land-use changes, the national land cover maps of 2000 (Landsat-based) and 2015 (SPOT-based) were harmonized and overlaid. In addition, a wall-to-wall Landsat-based tree cover change map of 2000-2014 was integrated with the land cover change map and zonal statistics of tree cover change data were computed. This integration enabled the calculation of the average percentage of tree cover for each polygon of the land cover change map for the years 2000 and 2015. Moreover, Tier 2 values of above-ground biomass stocks were used to calculate the carbon stocks in 2000 and 2015 as the product of percentage tree cover and average biomass per percentage tree cover for each polygon of the land cover change map. We estimated that the total emissions from deforestation and degradation were 1,188,971 tCO2e/year at the national scale. Moreover, removals from afforestation/reforestation and forest restoration activities were calculated at -814,718 t CO_2e/year. Also, the contribution of trees outside forest to the national emissions and removals was assessed even though were not accounted for FRL. The accuracy assessment of activity data and emission and removal factors was carried out based on stratified random sampling using confidence interval of 95%. The overall accuracy of activity classification was found to be 0.687 which indicates that our approach is effective and feasible for assessing emissions and removals from REDD+ related activities.

Keyowrds: deforestation, degradation, afforestation, reforestation, forest restoration

1. Introduction

Bangladesh, as a signatory country to the United Nations Framework Convention on Climate Change (UNFCCC) (ratified in 1994), is voluntarily submitting the National Forest Reference Emission Level/ Forest Reference Level (FRL) based on the decision 1/CP.16, paragraph 71(b), and measures mentioned in paragraph 70 of the same decision (UNFCCC 2011). The country welcomes the opportunity to avail the technical assessment of the FRL in accordance with the guidelines and procedures adopted under Decision 13/CP.19 (UNFCCC 2014), in the context of results-based payment for *reducing emissions from deforestation and forest degradation and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries (REDD+)*.

As one of the most vulnerable countries to climate change induced natural disasters, Bangladesh is fully aware of the causes of climate change (MoEFCC 2009). According to Bangladesh's Second National Communication on greenhouse gas (GHG) inventory to UNFCCC, submitted in 2012, the Land-use, Land-use Change and Forestry (LULUCF) sector was the second biggest contributor to CO_2 emissions in the country after the energy sector. The former sector contributed to about 31% of total CO_2 emissions while the latter sector contributed 64% of the total national emissions (MoEFCC 2012). Although no precise estimate is available, the LULUCF sector is thought to remain one of the biggest contributors to GHG emissions in the country. Consequently, reducing emissions from the LULUCF sector has become a priority to the Government of Bangladesh (GoB). Indeed, as a long-term strategy of GoB to reduce GHG emissions from LULUCF sector, the National REDD+ Steering Committee (RSC) was formed in July 2011. The REDD+ Readiness Roadmap was prepared and endorsed by the RSC in December 2012. Subsequently, in June 2013, the UN-REDD Programme invited Bangladesh to submit a REDD+ Readiness Preparation Proposal (R-PP), based on which the government is implementing UN-REDD Bangladesh National Programme since 2015. The goal of the National Programme is to support GoB to initiate the implementation of its REDD+ Readiness Roadmap by establishing necessary management processes, identifying strategic readiness options, and developing the capacities required to begin implementation of REDD+ activities. Hence, as a part of the National REDD+ Readiness Roadmap, the country has developed the FRL for submission to the UNFCCC.

2. Land cover maps 2000 and 2015

The Land Representation System (LRS) represents the land classes in the country based on a transparent, accurate, complete, comparable and consistent methodology for Bangladesh (GoB 2017). LRS is developed using the latest version of the Land Cover Classification System (LCCS v.3), which is a tool recognized by the International Organization for Standardization (ISO) for classifying land in an area.

The legends of the national land cover maps 2015 and 2000 have been prepared using the LRS of Bangladesh (Islam, Iqbal et al. 2016). In total, 33 land classes have been defined for the national land cover map of 2015 (GoB 2017), while 24 land classes have been defined for the national land cover map of 2000 (GoB 2017). These two maps have been used to calculate the activity data for the construction of FRL.

3. Tree Cover maps

In 2016, the Resources Information Management System (RIMS) unit of the BFD in collaboration with the Global Land Analysis and Discovery (GLAD) Laboratory of the University of Maryland published the tree cover change map of the country over the period of 2000 to 2014 (Potapov, Siddiqui et al. 2017). The tree cover mapping and monitoring system is based on the integrated use of wall-to-wall Landsat-based mapping and sample-based area estimation using freely available high spatial resolution imagery and Landsat time-series data.

A two-stage method for national tree cover monitoring was established. At the first stage, wall-to-wall Landsat-based tree cover extent and change maps were created. These maps served to stratify the whole country for the implementation of a stratified random sampling protocol (Potapov, Siddiqui et al. 2017). The second stage of the analysis consisted of characterizing tree cover area and change based on samples of multi-resolution time-series data. Stratified random sampling design was used based on Landsat-derived wall-to-wall maps as sampling strata. A set of 1486 samples consisting of 30 x 30 m Landsat pixels was visually interpreted to estimate fractional (% of pixel area) tree canopy cover and canopy loss and gain. Accuracy assessment of the tree cover maps were conducted (Potapov, Siddiqui et al. 2017). Though very useful to understand the tree cover gains and losses, the tree cover maps do not provide information on the forest or non-forest status of land. Since, these maps provide information on presence of trees, this information can be used within the land classes to detect gains or losses of trees, and therefore emissions or removals of CO_2

4. Integration of tree cover 2000-2014 maps

The entire Landsat archive for Bangladesh was used to derive nationally consistent input time-series data. Using Landsat data for the year 2000, pixels with greater than 50% tree cover were mapped to create a dataset “>50% tree cover extent stratum” (Potapov, Siddiqui et al. 2017). This >50% tree cover extent stratum map guided the change detection for the 2000 - 2014 time interval. A “gross tree cover loss stratum” was defined as pixels with greater than 50% tree cover in the year 2000 that lost tree cover from 2000 to 2014 (even if they gained tree cover by the year 2014).

A “gross tree cover gain stratum” was defined as pixels outside the year 2000 “>50% tree cover extent stratum” that increased canopy cover above 50% by the year 2014. The gross tree cover loss and gain stratum maps were produced independently. Wall-to-wall Landsat based tree cover extent and change maps were created.

For each polygon of the land cover change map zonal statistics of 2000-2014 tree cover (TC) change data were computed. This results in each polygon of the map containing the number of pixels with tree cover in 2000, the number of pixels with gains and the number of pixels with tree cover loss for each year between 2001 and 2014. The tree cover change was calculated for each polygon as the number of pixels with trees divided by the total number of pixels. The tree cover of 2015 was calculated by subtracting the total annual tree cover losses (2001-2014) from the tree cover of 2000 and adding the total tree cover gains obtained during the period 2001-2014.

$$TC_{2015\,i} = TC_{2000\,i} - TC_{loss_{2001-2014}} + TC_{gain_{2001-2014}} \quad \text{(Equation 1)}$$

Where

$TC_{2015\,i}$: percentage (%) of tree cover of polygon i, in 2015
$TC_{2000\,i}$: percentage (%) of tree cover of polygon i, in 2000
$TC_{loss_{2001-2014}}$: total annual percentage (%) of tree cover loss of polygon i from 2001 to 2014
$TC_{gain_{2001-2014}}$: total percentage (%) of tree cover gain of polygon i from 2001 to 2014

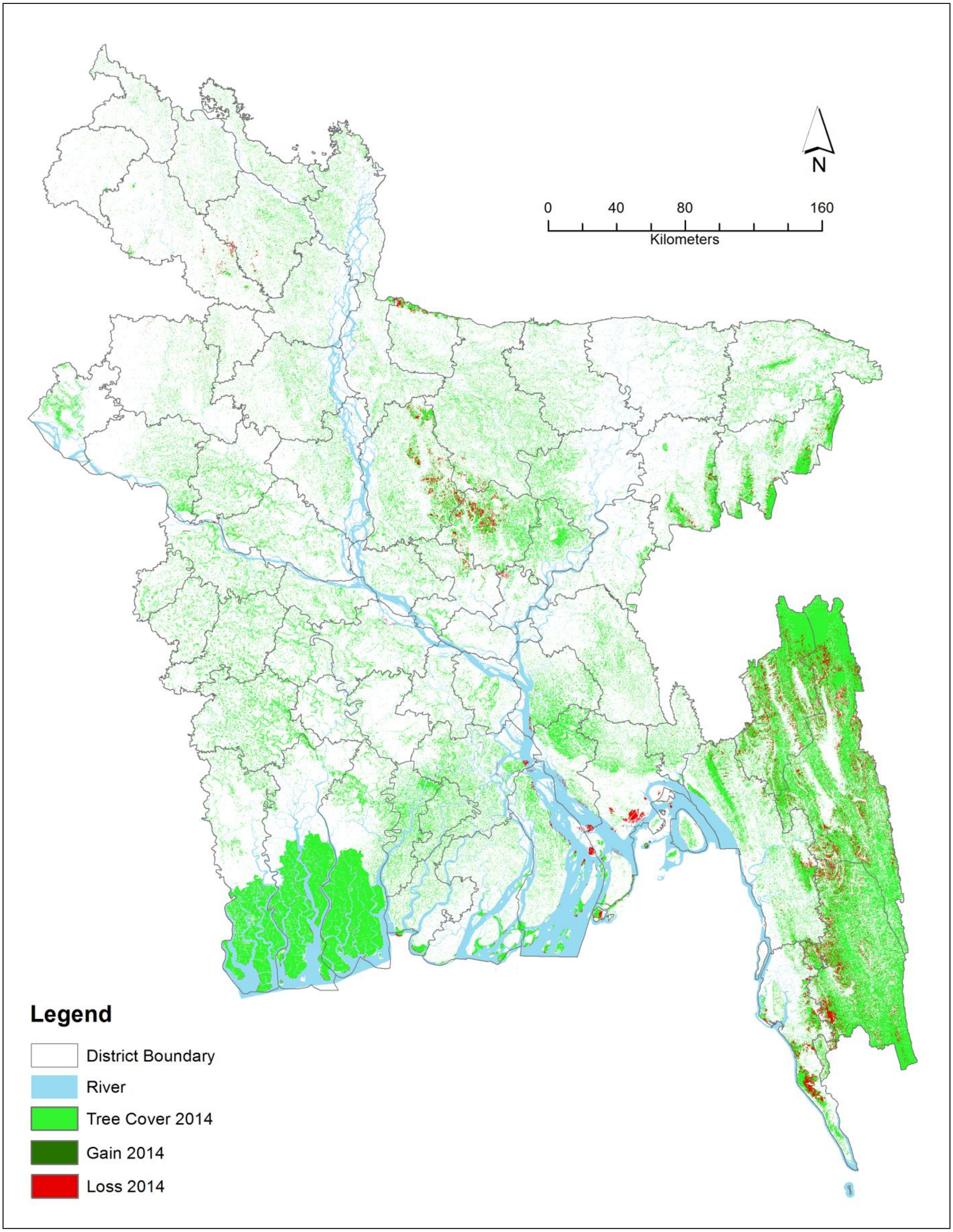

N
0
40
80
160
Kilometers
Legend
District Boundary
River
Tree Cover 2014
Gain 2014
Loss 2014

Figure 1: Tree cover change map 2000-2014 (Potapov, Siddiqui et al. 2017).

Each polygon of the integrated land cover change map and tree cover change contains the following information:
- area in hectares (ha)
- land class in 2000
- land class in 2015
- BFI zone in which the polygon is located
- percentage (%) of tree cover in 2000
- percentage (%) of tree cover in 2015.

4.1 Average percentage tree cover and average biomass per percent tree cover

With the information at the polygon on land class and tree cover percentage, the average percentage (%) of tree cover (avg_ptc) per land class was calculated as weighted average percentage (%) of tree cover (w_avg_ptc) of each polygon and their area, as follows:

$$avg\_ptc = \frac{\sum_i^n \left(area_{2000_i} \times ptc_{2000_i}\right) + \sum_i^m \left(area_{2015_i} \times ptc_{2015_i}\right)}{\left(\sum_i^n area_{2000i}\right) + \left(\sum_i^m area_{2015i}\right)} \qquad \text{(Equation 2)}$$

Where,

w_avg_ptc: weighted average percentage (%) of tree cover per land class
$area\_2000_i$: area (ha) of polygon **i** in 2000
ptc_2000_i percentage (%) of tree cover of polygon **i** in 2000
$area\_2015_i$: area (ha)of polygon **i** in 2015
ptc_2015_i percentage (%) of tree cover of polygon **i** in 2015
n: number of polygons of a land class in 2000
m: number of polygons of a land class in 2015

Table1 shows the weighted average percentage (%) of tree cover per land class used in the FRL.

The average above-ground biomass (t/ha) per percentage (%) of tree cover (agb_per_ptc) was calculated for each land class **i**

$$agb\_ptc_i = \frac{w\_agb\_class_{\ i}}{w\_avg\_ptc_i} \qquad \text{(Equation 3)}$$

agb_ptc_i: above-ground biomass (t/ha) per percentage (%) of tree cover for a land class i

$w\_agb\_class_{\ i}$: weighted above-ground biomass (t/ha) for a land cover class i
$w\_avg\_ptc_i$: weighted average percentage (%) of tree cover for a land cover class **i**

Table 1: Weighted average above-ground biomass (w_agb_class), weighted average percentage of tree cover (w_avg_ptc) and above-ground biomass per percent tree cover (agb_ptc) of each of the harmonized FRL land use classes. NA: not available

	Land classes used in the FRL	**w_agb_class (ton/ha)**	**w_avg_ptc (%)**	**agb_ptc (ton/ha/%)**
1	Forest Tree Dominated Area (Aquatic/ Regularly Flooded)	-	44	0
2	Forest Tree Dominated Area (Terrestrial)	55.198	79	0.699
3	Herbaceous Crops	-	2	0
4	Herb Dominated Area	6.220	1	6.22
5	Mangrove Forest	95.199	94	1.013
6	Mangrove Plantation	43.424	62	0.7
7	Mud Flats or Intertidal Area	-	1	0
8	Non-vegetated	-	4	0
9	Orchards and Other Plantations (Trees)	44.676	28	1.596
10	Plain Land Forest (Sal Forest)	61.479	69	0.891
11	Rivers and Khals	-	1	0
12	Rubber Plantation	36.030	66	0.546
13	Rural Settlement	27.493	33	0.833
14	Shrubs with scattered trees	9.316	44	0.212
15	Swamp Reed Land	-	5	0

4.2 Emission and removal factors

Knowing for each polygon the land class in 2000 (i) and 2015 (j), the percentage (%) of tree cover in 2000 (ptc_{2000}) and 2015 (ptc_{2015}) and the average biomass per percent tree cover (agb_per_ptc), the emission or removal factor (efrf in tCO_2e/ha) for each polygon is calculated as follows in Equation 4:

$$efrf_{i,j} = ptc_{2000} \times agb\_per\_ptc_i - ptc_{2015} \times agb\_per\_ptc_j \times 1.2 \times 0.47 \times \frac{44}{12}$$

or

$$efrf_i = (ptc_{2000} - ptc_{2015}) \times agb\_per\_ptc_i \times 1.2 \times 0.47 \times \frac{44}{12} \qquad \text{(Equation 4)}$$

In Equation 4, the land class has changed between 2000 and 2015. In Equation 5, the land class remains the same. The below-ground biomass was calculated using the R ratio. The carbon fraction used was 0.47 (IPCC 2006)and the ratio C to CO_2 was 44/12. The factor 1.2 is used for the conversion of aboveground biomass to total tree biomass (above and belowground). The IPCC default root to shoot ratio of 0.2 was taken from 2006 IPCC guidelines Chapter 4 table 4.4, mixed deciduous forest as a conservative value.

Emission and removal factors are applied to each polygon. They can be averaged to land cover change classes (EFRF) by applying a weighted average:

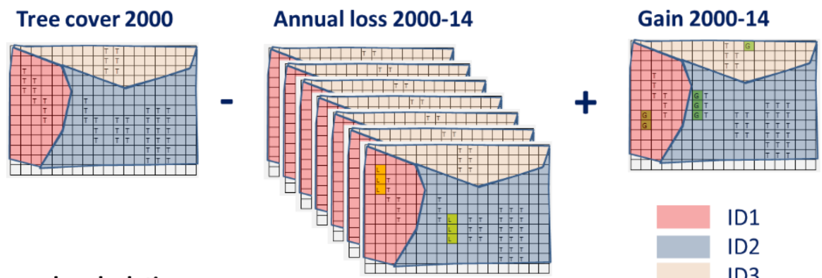
$$EFRF_{i,j} = \frac{\sum_k^n (area_{i,j,k} \times efrf_{i,j,k})}{\sum_k^n (area_{i,j,k})} \qquad \text{(Equation 5)}$$

Where

n: number of polygons of class **i** in 2000 and **j** in 2015
k: number of polygons changing from a class **i** in 2000 to **j** in 2015
$area_{i,j,k}$: area of polygons that changed from a land class **i** in 2000 to land class **j** in 2015
$efrf_{i,j,k}$: emission/removal factors that result from a change of land class **i** in 2000 to land class **j** in 2015

4.3 Calculation of percentage of tree cover change in land cover change polygon

- Example illustrated below for three land cover class – ID1, ID2 and ID3



Example calculation

- 9 pixels covered by tree in 2000 in ID1 (18% tree cover)
- 3 pixels loss of tree cover between 2000-14 in ID1
- 2 pixels gained tree cover between 2000-14 in ID1
- Total pixel in ID1 is 50
- Tree cover in ID1 in 2014 is (9 – 3 + 2)/50 = 16%
- **Tree cover change in ID1 is 16 – 18 = -2%**

Assign activity based on the definition

ID	LC 2000	LC 2015	LC change	TC 2000	TC 2015	TC change	F2000	F2015	Activity
1	A	A	A to A	18	16	-2	F	F	Forest stable
2	A	B	A to B	40	53	13	F	NF	Deforestation
3	A	A	A to A	18	10	6	F	F	Degradation low
4	A	A	A to A	18	25	7	F	F	Restoration or reforestation; based on the location

** TC = Tree Cover, LC = Land Cover, F = Forest, NF = Non forest

Table 1: Activity data (ha/year) of REDD+ activities for BFI zones and national level.

	Activity data (ha/year)						
BFI zones	REDD+ activity						Non-forest stable
	Deforestation	Degradation High	Degradation Low	Enhancement			
				Aforestation/reforestation	Restoration High	Restoration Low	
Coastal	780.99	46.06	147.43	642.80	3451.54	2617.30	56717.99
Hill	8963.15	2203.43	7543.92	7153.68	998.22	1501.14	51586.40
Sal	138.70	986.05	511.08	255.79	505.84	379.45	32115.13
Sundarban	157.55	0.30	11.20	158.82	81.08	280.78	12667.75
Village	87.05	78.56	50.04	439.10	178.95	146.39	724204.17
National	10127.44	3314.39	8263.67	8650.19	5215.64	4925.07	877291.43

The emission and removal factors (tCO2eq/ha) that were used to calculate the associated emissions and removals at the national and BFI zones are reported in ***Error! Reference source not found.****.*

Table 3: Emission and removal factors (tCO_2eq/ha) for REDD+ activities for the BFI zone and national level.

BFI zones	**Emission and removal factors (tCO_2eq/ha)**						
	REDD+ activity						Non-forest stable
	Deforestation	Degradation high	Degradation low	Enhancement			
				Afforestation/ Reforestation	Restoration high	Restoration low	
Coastal	51.44	37.43	17.97	-60.42	-60.08	-15.43	-1.33
Hill	83.77	61.78	16.00	-47.67	-62.85	-15.96	0.60
Sal	95.79	87.23	26.24	-39.57	-56.72	-18.37	0.74
Sundarban	75.29	66.67	16.43	-30.50	-165.92	-18.53	-0.22
Village	42.47	92.72	19.50	-38.31	-67.79	-15.04	-0.62
National	80.95	69.75	16.69	-47.59	-62.20	-15.98	-0.54

Total emissions and removals ($t CO_2e/year$) associated with the REDD+ activities at the national and BFI zones are given in Table 2 below. The numbers within the parentheses are the confidence intervals (%).

Table 2: Emissions and removals ($t CO_2e/year$) from REDD+ activities at the zone and national level.

BFI zones	**Emissions and removals ($tCO_2e/year$)**						
	REDD+ activity						Non-forest stable*
	Deforestation	Degradation High	Degradation Low	Enhancement			
				Afforestation/Reforestation	Restoration High	Restoration Low	
Coastal	40,173 (16)	1,724 (44)	2,650 (57)	-38,841 (45)	-207,371 (83)	- 40,378 (38)	-75,216 (7)
Hill	750,878 (28)	136,134 (43)	120,726 (57)	-340,993 (29)	-62,742 (72)	-23,953 (32)	31,118 (6)
Sal	13,286 (20)	86,012 (28)	13,412 (36)	-10,121 (25)	-28,693 (52)	-6,969 (23)	23,658 (46)
Sundarban	11,862 (35)	20 (45)	184 (58)	-4,844 (69)	-13,453 (84)	-5,202 (38)	-2,749 (57)
Village	3,697 (19)	7,284 (38)	976 (33)	-16,821 (30)	-12,131 (58)	-2,201 (24)	-449,336 (1)
National	819,854 (26)	231,175 (35)	137,942 (51)	-411,623 (26)	-324,390 (60)	-78,705 (24)	-476,084 (2)
Emissions/Removals from non-forest stable (trees outside the forest) were not accounted for FRL							

5. Proposed forest reference level

Table 3: Emission and Removal (t CO_2e/year) at the zone and national level. The numbers within the parentheses are confidence interval (%).

BFI zones	**Emissions**	**Removals**
	tCO_2e/year	**tCO_2e/year**
Coastal	44,547 (15)	- 286,590 (61)
Hill	1,007,738 (23)	- 427,688 (25)
Sal	112,710 (22)	- 45,783 (33)
Sundarban	12,066 (34)	- 23,499 (51)
Village	11,957 (24)	- 31,153 (28)
National	**1,188,971 (20)**	**- 814,718 (27)**

The emission estimated from deforestation and forest degradation for the period of 2000-2015 of Bangladesh is 1,188,971 tCO_2e/year. Removal estimated from afforestation/reforestation and forest restoration is - 814,718 tCO_2e/year (Table 3). The net change, FRL, is 374,253 tCO_2e/year.