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RESEARCH ARTICLE

Assessment and monitoring of deforestation and forest fires in Bangladesh using remote sensing data

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ABSTRACT
There has been a growing global interest in the evaluation of the conservation effectiveness and monitoring of changes in forests. Bangladesh represents tropical semi-evergreen forests, moist deciduous forests, dry deciduous forests and mangroves. This study has determined the state of forest cover change and fire regimes and attempted to give insight on carbon emissions. There is a significant rate of deforestation in open moist deciduous forests, followed by open dry deciduous forests, dense moist deciduous forests and open semi-evergreen forests. An ascending trend in the total number of fire incidences per year has been noticed in the forests of Bangladesh. This study would provide a valuable basis for developing biodiversity conservation plans and the implementation of restoration programs for degraded forest ecosystems.

KEYWORDS: Forest; deforestation; fire; emissions; conservation.

Introduction

Deforestation and forest fires are a major contributor to global environmental problems having a direct impact on biodiversity and play a significant role in atmospheric chemistry. Monitoring of forest cover is being valued more than ever before, because of the recognition of ever-increasing anthropogenic pressure on forests. In 2010, the Convention on Biological Diversity committed to the Strategic Plan for Biodiversity (2011–2020) including 20 Aichi Biodiversity Targets to be achieved by 2020 (CBD, 2010). Biodiversity Target 5 aims to halve global deforestation rates by 2020. Satellite-based Earth Observation is the only global monitoring tool adequate for assessing the status and trends of ecosystems. During 1990-2005, there was a net decrease in the global forest area of 1.7% (FAO, 2005). Hansen et al. (2010) reported the global gross forest cover loss during 2000–2005 was 0.6% per year. Bangladesh, a coastal country of Asia, extending over 147,570 km^2 in the north-eastern part of South Asia and a part of Indo-Burma Global Biodiversity Hotspot. It has Sundarbans, the largest single tract of the mangrove ecosystem in the world. It is the eighth most densely populated country in the world represents 2.15% of the global population (http://www.bbs.gov.bd/). According to FAO (2005), the majority (64.2%) of land is under agricultural use and only 10.2% of the total land is under forest cover. The total forestland includes classified and unclassified state lands, homestead forests and tea and rubber gardens. Of the 2.53 million ha of forest land, the Forest Department manages 1.53 million ha including hill,

Sal and Sundarban mangroves (Alam 2008). The protected area network of the country represents 1.4% of the surface area, one of the smallest proportions of protected forest in the world. Few long-term studies are using coarse to moderate resolution data to capture the broad extent and spatial patterns of forest cover change. Reddy et al. (2016) reported that the forests in Bangladesh had a net loss of 39.1% of forest area from 1930 to 2014. Continuous monitoring at a national scale permits identification of areas experiencing high degrees of deforestation (Ingram and Dawson, 2005).

This study mapped the extent of forest cover, forest burnt area and analyzed changes in the forest cover, distribution of forest fires and estimated carbon emissions due to fires.

Methodology

Forest cover and forest burnt area assessment

Multi-season orthorectified Landsat 8 OLI data of 2017 with 30m spatial resolution were downloaded from USGS Earth Explorer (https://earthexplorer.usgs.gov/). The spatial forest cover and forest type map of 2014 (Reddy et al. 2016) was referred to add corresponding changes using hybrid classification techniques and to analyse changes across forests from 2014 to 2017. To overcome issues of phenological variations, hybrid classification techniques including the combination of NDVI, object-based image analysis, and visual image interpretation were used to map forest cover and forest burnt area using Landsat OLI data of 2017. In this study, deforestation is considered as the replacement of natural forest by other land use and/ or depletion of forest canopy cover to less than 10%. Landsat 8 OLI data of the summer months i.e., March, April, and May of 2017 were used to map forest burnt areas.

The annual rate of deforestation within each district and for different forest types was estimated by comparing the temporal data. The equation for the annual rate of deforestation is derived from the compound interest formula due to its explicit biological meaning (Puyravaud, 2003).

$$P = \frac{100}{t_2 - t_1} \ln \frac{A_2}{A_1}$$

Where r is the annual rate of change (percentage per year), a_1 and a_2 are the forest cover estimates at time t_1 and t_2 respectively. In addition to the assessment of forest cover changes within different states, a similar spatial analysis was also conducted to assess the forest cover changes occurred within different forest types. Classification accuracy was evaluated using high-resolution Google Earth images (https://www.google.com/intl/en_in/earth/).

Monitoring of forest fires

Visible Infrared Imaging Radiometer Suite (VIIRS) is a sensor that has been operating onboard the Suomi NPP (National Polar-orbiting Partnership) satellite. VIIRS active fire locations from 2017 to 2019 (https://earthdata.nasa.gov/earth-observation-data/near-realtime/firms/active-fire-data) were used for spatial analysis. The fire algorithm uses all five 375 m VIIRS channels to detect fires and separate land, water and cloud pixels in the image. This higher spatial resolution enables VIIRS to detect fires that MODIS overlooks. To illustrate fire regimes, daily VIIRS data on active fire locations for 2017 to 2019 were combined into 5 km x 5 km grid cells. The fire points across the forest grid cells were used to estimate fire frequency and fire density.

Estimation of carbon and other trace gas emissions

The parameters considered for the estimation of carbon and other trace gas emissions are the amount of forest area affected by fire, calculation of the biomass burnt, the amount of fuel load (emission ratio), burning efficiency and the emission factor for the gas (smoke) emitted. Carbon emissions were estimated from the mathematical expression (Sieler and Crutzen, 1980; Andrea and Merlet, 2001). The emission factor for carbon emissions from fire for different vegetation types was derived from Andreae and Merlet (2001). For the tropical forests, the values of dry matter and combustion efficiency given by Badarinath and Prasad (2011) have been used. The emission factors were multiplied with the conversion factors and the units were set to the range of equations and thus calculated for different forest types.

$$E = A \times B \times ß \times EF$$

Where, E is the emissions (in CO_2 grams),

A is the total land area burned (m^2),

B is the Average biomass/fuel load (kg/dry matter/m^2),

ß is the burning efficiency of above-ground biomass and

EF is the Emission factor (Mass of species per mass of dry matter burned in g/kg)

Results and Discussion

Key findings of the study

1. Analyzed deforestation across forest types
2. Mapped forest burnt area
3. Analyzed spatial and temporal patterns of fires
4. Estimated greenhouse gas emissions from forest fires

Forest cover and change analysis

From the classified maps of 2017, it is understood that 9.4% of the total geographical area of Bangladesh is covered by forest and it occupies an area of 13818 km^2. From 2014 to 2017 the percentage of the annual rate of deforestation was estimated at 0.64%. The earlier study conducted by Reddy et al. (2016) reported the percentage of annual rate of deforestation was 0.74% in 1930-1975, 0.47% in 1975-1985, 0.26% in 1985-1995, 0.53% in 1995-2006, and 0.75% in 2006-2014. Annual net rate of deforestation in Bangladesh was shown in Figure 1. Forests of Bangladesh show large scale deforestation due to shifting cultivation and other human-induced activities. Despite the conservation measures taken, the deforestation rate in Bangladesh seems to be very high as compared to neighbouring South Asian countries (Reddy et al. 2018).

Dry deciduous forest is the predominant type of forest in Bangladesh which occupies an area of 6100 km^2 and it accounts the 44.1% of the total forest area, followed by mangrove forest which covers 30.5% of the total forest area, moist deciduous forest occupies 19.2% of the forest area, and semi-evergreen forest covers 6.2% of the total forest area (Fig. 2). Forest type maps of 2014 and 2017 were compared to estimate forest area change in each forest ecosystem from 2014 to 2017 (Table 1). The analysis reported that from 2014 to 2017 a total of 268 km^2 of forest area was lost. In that major loss of forest cover was found in the open dry deciduous forest (201 km^2), followed by dense moist deciduous forest (33 km^2), open moist deciduous forest (29 km^2), and open semi-evergreen forest (4 km^2). The annual rate of deforestation was found high in the open moist deciduous forest (1.64%) followed by open dry deciduous forest (1.08%), dense moist deciduous forest (0.53%) and open semi-evergreen forest (0.21%). No deforestation was recorded in dense semi-evergreen forests and mangroves (Table 1).

In Bangladesh, the natural forest is distributed in twenty-three districts (Fig. 3). Among the twenty- three districts, Parbattya Chattagram (22.57%), Bandarbon (19.13%) and Khagrachari (12.77%) have more than 10% forest area with respect to their total geographical area. Eight districts in the South-Eastern part of Bangladesh show significant deforestation.The annual rates of deforestation for Bandarbon (2.03%), and Cox's Bazar (1.46%) were estimated as highest and have a greater deforestation rate than the annual deforestation rate of the country i.e. 0.64%. Annual rate of deforestation estimated in other districts are as follows; Chittagong (0.61%), Parbattya Chattagram (0.58%), Brahmanbaria (0.41%), Khagrachari (0.32%), Noakhali (0.11%) and Hobiganj (0.01%). Rahman et al. (2008) reported that one-eighth of the country's land area is affected by deforestation due to land clearances for agriculture, principally through shifting cultivation in the hill forests. Other causes of deforestation and degradation include encroachment, grazing, fire, logging, and fuelwood collection (BBS, 2008; UN-REDD 2017). A hundred places where change was detected were validated against very high- resolution Google Earth data. Overall classification accuracy was estimated at 91.12%.

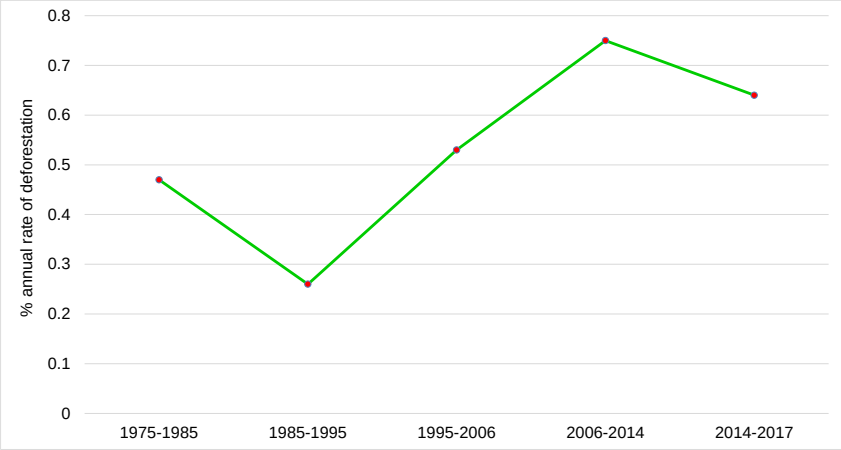

Fig. 1. Annual rate of deforestation in Bangladesh (Reddy et al. (2016) and present study)

Table 1. Distribution of forest cover and change across forest types: 2014-2017 (area in km^2)

Sl.no.	Forest type	2014	2017	Change (km^2)	Annual rate of deforestation (%)
1	Semi-evergreen forest				
1a	Dense Semi-evergreen Forest	217	217	0	0.00
1b	Open Semi-evergreen Forest	638	634	-4	-0.21
	Subtotal	855	851	-4	-0.16
2	Moist Deciduous Forest				
2a	Dense Moist Deciduous Forest	2107	2074	-33	-0.53
2b	Open Moist Deciduous forest	604	575	-29	-1.64
	Subtotal	2711	2649	-62	-0.77
3	Dry Deciduous Forest				
3a	Open Dry Deciduous forest	6301	6100	-201	-1.08
	Subtotal	6301	6100	-201	-1.08
4	Mangrove forest			0	
4a	Dense Mangrove forest	4179	4179	0	0.00
4b	Open Mangrove forest	40	40	0	0.00
	Subtotal	4219	4219	0	0.00
	Grand total	14086	13818	-268	-0.64

Estimation of forest burnt area

In Bangladesh 2318 km^2 of the forest area was affected by forest fires which accounts for 16.8% of the total forest area of the country. The estimate shows that 29.3% of the total area of dry deciduous forests was affected by fires in 2017. Following dry deciduous forests, the burnt areas were reported very high in the semi-evergreen forest, in which 20.3% of the total area of that forest was found burned. In the open moist deciduous forest, the burnt area was found in 16.5% of the total area of that forest, in the dense moist deciduous forest it was found as 12.6%, and in the dense semi-evergreen forest the percentage of the total burnt area was found as 3.7%. The estimate of burned area distribution across the forest types in Bangladesh is given in Table 2.

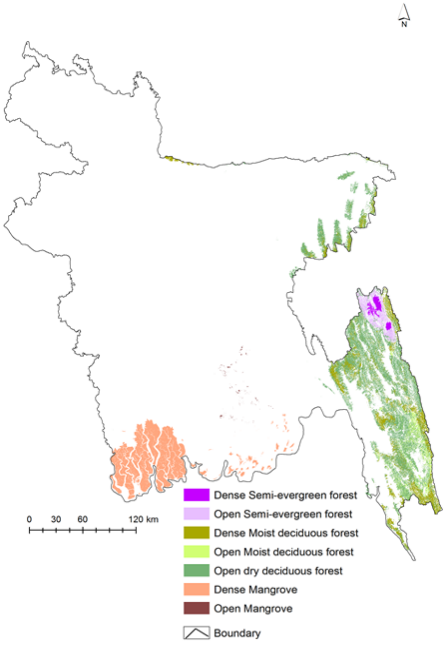

Fig. 2. Forest type map of Bangladesh: 2017

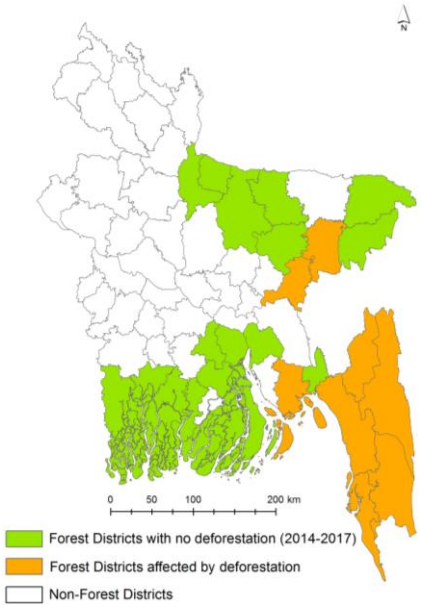

Fig. 3. Map showing districts affected by deforestation from 2014 to 2017

Table 2. Burned area distribution across the forest types in Bangladesh: 2017 (area in km^2)

Sl.no.	Forest type	Burnt area (km^2)	% of forest burnt area
1	Semi-evergreen forest		
1a	Dense Semi-evergreen forest	8	3.7
1b	Open Semi-evergreen forest	165	26.0
	Subtotal	173	20.3
2	Moist Deciduous forest		
2a	Dense Moist Deciduous forest	262	12.6
2b	Open Moist Deciduous forest	95	16.5
	Subtotal	358	13.5
3	Dry Deciduous forest		
3a	Open Dry Deciduous forest	1788	29.3
4	Mangrove forest	0	0.0
	Grand total	2318	16.8

Monitoring of fires

The number of fire incidences shows an increasing trend from 2017 (i.e. 3190 locations to 2019 (i.e. 5644 locations) which indicates the high threat to the existence of native species of Bangladesh. Spatial analysis shows a peak of the fire season in Bangladesh which is mostly occurring from March to April (Table 3). Out of the 1587 forest grid cells in Bangladesh, 733 (46%) grid cells were affected by fires from 2017 to 2019 (Fig. 4). Fire data for Bangladesh indicates 50% of forest grid cells were affected by fires as detected by MODIS during the period 2003 to 2017 (Reddy et al. 2019). Grid wise analysis indicates the number of grid cells affected by fires varies in 2017, 2018 and 2019 (Table 4). Fire frequency map shows 61.9% (454) of forest grids were affected in all these three years, followed by 19.1% (140) of the grids were affected in any two years and 19% (139) of the grids had fire occurrence in any one year (Fig. 5).

Table 3. Month-wise distribution cumulative fire locations in forests of Bangladesh

Month/Year	2017	% of fires	2018	% of fires	2019	% of fires
January	51	1.6	13	0.3	43	0.8
February	142	4.5	26	0.6	47	0.8
March	674	21.1	3138	68.1	3218	57.0
April	2230	69.9	1392	30.2	2271	40.2
May	83	2.6	8	0.2	12	0.2
June	2	0.1	0	0.0	8	0.1
July	0	0.0	0	0.0	0	0.0
August	0	0.0	1	0.0	0	0.0
September	0	0.0	0	0.0	0	0.0
October	3	0.1	6	0.1	0	0.0
November	5	0.2	22	0.5	34	0.6
December	0	0.0	5	0.1	11	0.2
Grand total	3190	100.0	4611	100.0	5644	100.0

Table 4. Spatial distribution of fire incidences across grid cells from 2017 to 2019

Fire density class	Count in 2017	Count in 2018	Count in 2019	Combined density
1	140	104	91	90
2-3	127	113	116	101
4-10	200	181	187	156
11-25	95	157	166	162
26-50	12	30	60	141
51-100	0	1	1	81
101-500	0	0	0	2
No fire	1013	1001	966	854

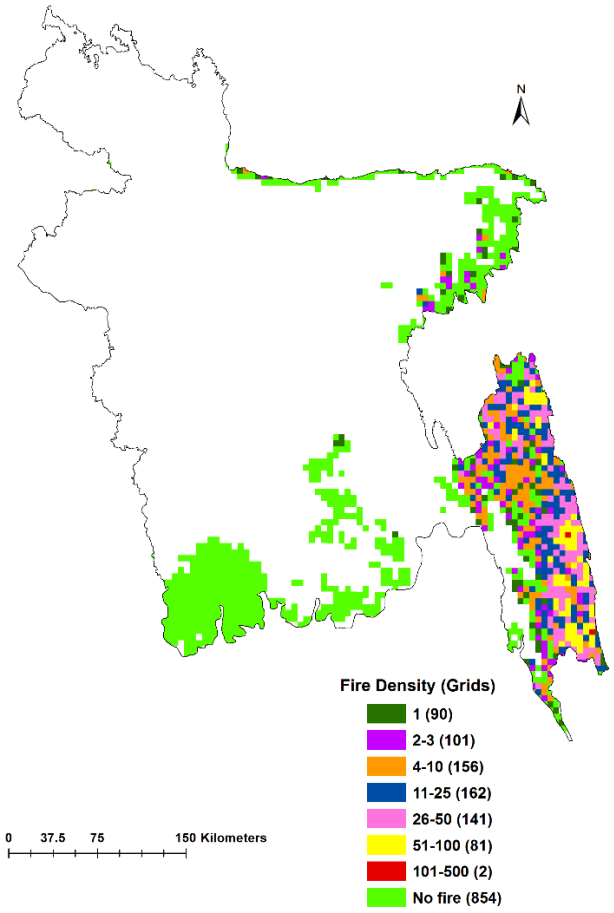

Fig. 4. Forest fire density map of Bangladesh (2017 to 2019)

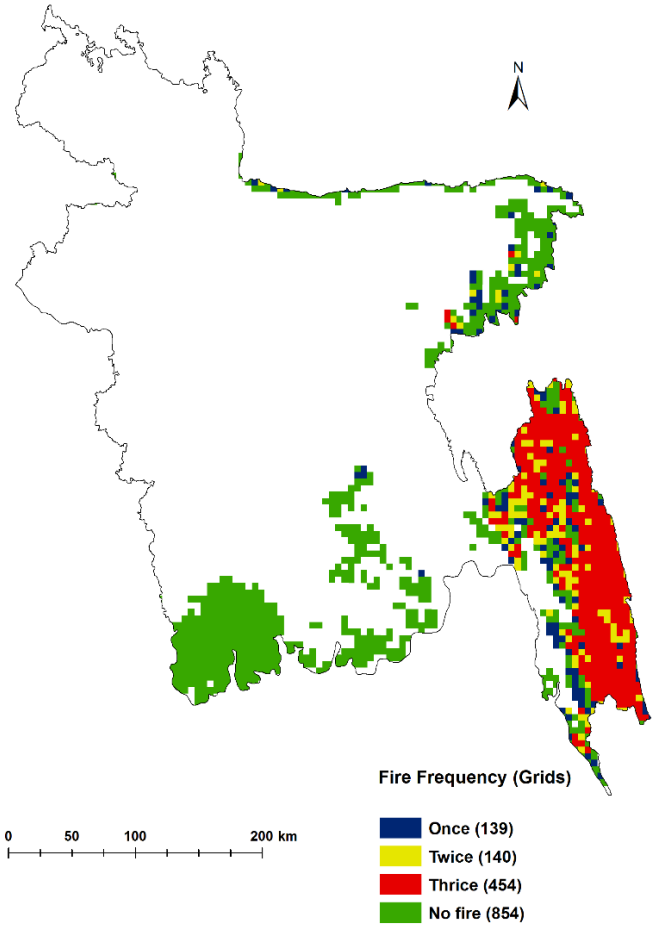

Fig. 5. Forest fire frequency map of Bangladesh (2017 to 2019)

Estimation of greenhouse gas emissions

Estimation of carbon emissions in Bangladesh reveals that about 4336.23 Gg yr^{-1} (=4.33623 Tg) CO_2 has been emitted due to fires in 2017. Among different forests, open dry deciduous type of forest contributes about 70.4% (i.e. 3050.55 Gg yr^{-1}) of CO_2 emissions followed by the dense moist deciduous type of forest with 13.9% of CO_2 emissions (Table 5). The amount of emission of other trace gases such as CO, CH_4, NO_x and N_2O due to fires were also calculated and the amounts were reported as 297.6 Gg yr^{-1}, 18.66 Gg yr^{-1}, 4.391 Gg yr^{-1}, and 0.549 Gg yr^{-1} respectively (Table 5). The total CO_2 emissions from forest fires in India were estimated to be 72,670 Gg during 2014 (Reddy et al. 2017).

Table 5. Emissions of carbon and other trace gases (Gg/Yr) for 2017

Forest type	CO_2	CO	CH_4	N_2O	NO_x
Dense Semi-evergreen forest	22.94	1.51	0.10	0.003	0.023
Open Semi-evergreen forest	496.86	32.70	2.14	0.063	0.503
Dense Moist deciduous forest	603.62	51.96	2.60	0.076	0.611
Open Moist deciduous forest	162.27	10.68	0.70	0.021	0.164
Open Dry deciduous forest	3050.55	200.80	13.13	0.386	3.089
Total	4336.23	297.65	18.66	0.549	4.391

Conclusions

The study tried to assess the status of the forests in Bangladesh using multi-temporal remote sensing data. The highest annual rate of deforestation was found in open moist deciduous forests (1.64%) during 2014 to 2017. In this work, areas of forest cover loss and fire incidences were presented to highlight management interventions. Future forest monitoring should include a combination of spatially extensive satellite remote sensing and in stu observations. The spatial data generated on the total area under forest cover, rate of deforestation, changes across forest types, forest burnt area, fire monitoring as well as greenhouse gas emissions would be useful in understanding the conservation effectiveness and thus strengthening sustainable forest management.

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