Chapter

Assessment of Ecological Disturbance Caused by Flood and Fire in Assam Forests, India, Using MODIS Time Series Data of 2001-2011

Dibyendu Dutta, Akanksha Balha, Prabir Kumar Das, Pragyan Jain, Libeesh Lukose and Wasim Akram

Abstract

The forest area of Assam State is known for its rich biodiversity. In the present study, the disturbance regime within the Assam forest area caused by periodic flood and forest fire, was assessed using the Moderate Resolution Imaging Spectroradiometer (MODIS) time-series (2001–2011) data. The MODIS Global Disturbance Index (MGDI) images were generated using MODIS derived Enhanced Vegetation Index (EVI) and Land Surface Temperature (LST) images. The temporal intensity of flood and forest fire in sixteen representative forests was analyzed to develop the MGDI based thresholds for detecting the disturbed area. The threshold for the non-instantaneous disturbance, i.e. flood, was found to be 107% whereas it was 111% for instantaneous disturbance, i.e. forest fire. The thresholds were applied on the MGDI images to delineate disturbed caused by flood and fire, separately for each year. The time-series disturbance areas were integrated over the years (2001–2011) to generate the classified disturbance prone maps.

Keywords: ecological disturbance, MGDI, flood, forest fire, Assam forest, MODIS, EVI, LST

1. Introduction

The north-eastern state of Assam is known for its rich biodiversity and considered as biological hotspot with many rare and endemic plant and animal species. Out of total 78,438 sq. km geographical area of the state, the forest area covers around 24.58% area. The moderate dense forests areas which are mainly extended through districts of Karbi Anglong, NC Hills, Cachar, Karimganj, Hailakandi, northern part of Kokrajhar, Bongaigaon and southern part of Kamrup, Tinsukia, are vulnerable to frequent flood incidents. The Brahmaputra River and its tributaries, flowing from north-east to south-west, are the mainly responsible for the periodic floods in Assam State. Along with flood events, the incidence of forest fires in the deciduous forests during summer season, i.e. March to April, causing a wide spread disturbance in the forest eco-system. Assam State has 5 National Parks and 16 Wildlife Sanctuaries under protected area (PA) network and constituting 4.98% of the geographical area. The protected areas can act as benchmark for differentiating the ecological disturbance from the natural fluctuation [1]. Hence, regular monitoring of PA's is crucial for detecting the rapid changes in functional attributes as well as to identify areas that need to adapt or modify to meet the challenges posed by global warming [2].

The understanding of the global carbon cycle is being affected due to the existing spatio-temporal variability of eco-system disturbance and resultant emissions from loss of terrestrial biomass [3–8]. Hence, the regular monitoring and assessment of the ecological disturbance is essential for understanding the cause and effect of the disturbances and subsequent effective management of the forest ecosystems. With the advent of multispectral and thermal remote sensing technology, the earth observation satellites data became more effective for monitoring biodiversity. The altered ecosystem structure and functions due to sustained disturbance in Woody ecosystem can be captured by remote sensing for mapping the extent and location of the disturbance [9, 10]. The effectiveness of the management practices or impact of global environment changes in the forest areas, especially Protected Area (PA), can be successfully carried out using satellite remote sensing [11, 12]. The technology can also provide valuable information on the alteration of landuse, productivity or phenology [13].

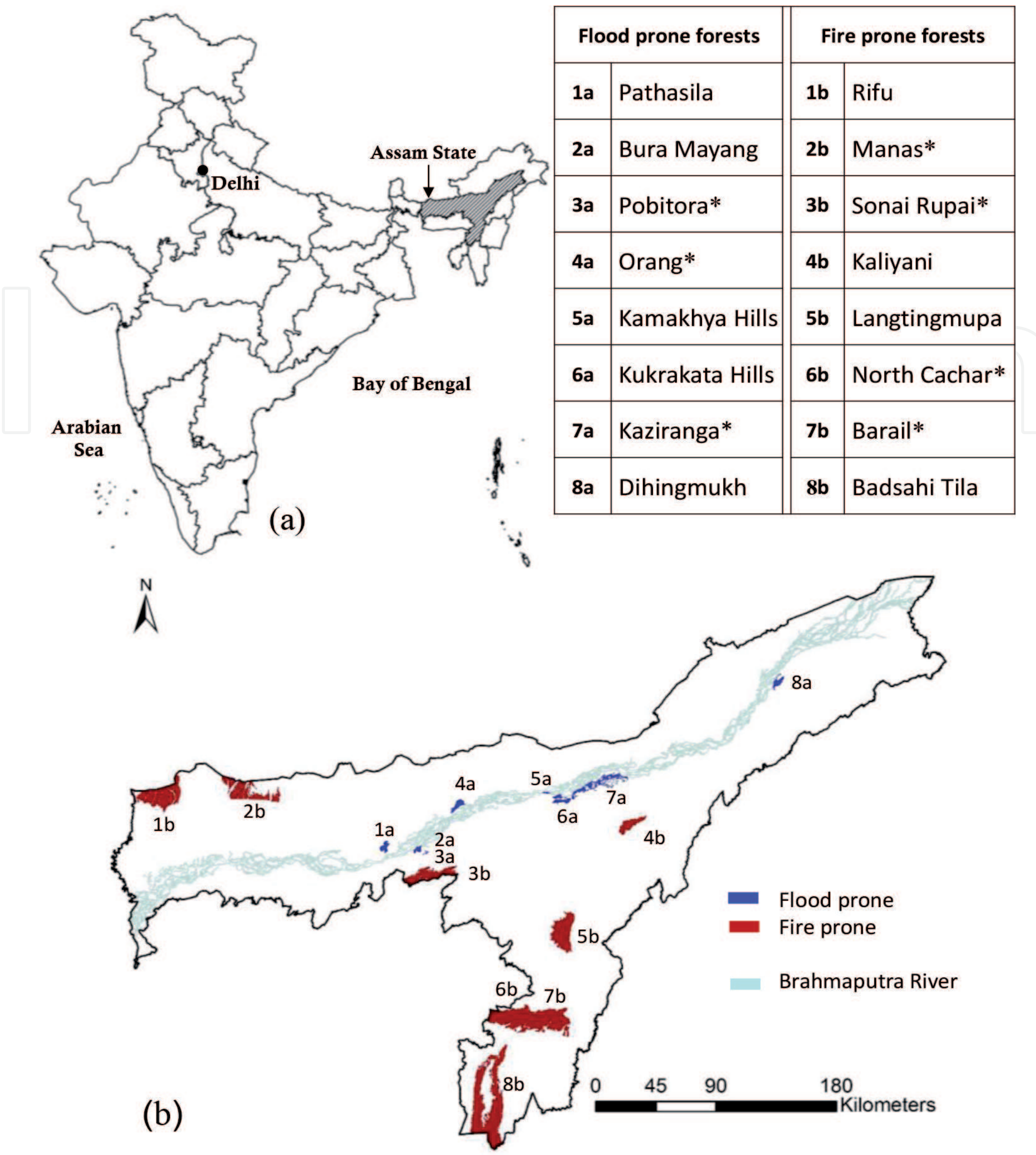
The MODIS global disturbance index (MGDI) was first proposed and used by [14] for assessing the disturbance in woody ecosystems of North America. The MGDI was conceptualized based on the fact that the surface temperature decreases with the increase in vegetation density through the latent heat transfer [15, 16]. The index was further utilized for assessing the impact of cyclones on the ecological disturbance of mangrove forest of Sundarbans. For further details about the concept and computation of MGDI, one can refer [14] or [16].

In the present study, MODIS global disturbance index (MGDI) was used to assess the ecological disturbance caused by two different kinds of natural hazards, viz. river flood and forest fire, in the perennial forest ecosystem of Assam State during 2001 to 2011. The flood and forest fire induced disturbed areas were identified based on the MGDI based thresholds and the spatio-temporal dynamics of the disturbance over the Assam forest area was studied. Finally, a classified geo-spatial product of disturbed prone forests was generated based on estimated disturbed area during the entire study period.

2. Study area

Assam State, situated at the north-east of India and foothills of the eastern Himalayas, covers an area of 78,438 sq. km and lies in the middle reach of the Brahmaputra River and Barak (http://www.asbb.gov.in/geophysical.html). The state is bounded by 88.25°E to 96.00°E longitude and 24.50°N to 28.00°N latitude (**Figure 1**). Mean annual temperature varies from 6–38°C and average annual rainfall is 3000 mm on the Brahmaputra River valley and the surrounding region. In Assam State around 51 types of forests and sub-forests can be found. Physiographically the state can be classified into 3 groups, viz. vast alluvial plains of the Brahmaputra River valley in the north, the central Assam hills and the hilly and alluvial terrain in the south.

In the present study, the ecological disturbance regime of the Assam forest area, India has been analyzed. Based on the intensity of flood and fire incidence, total 16 forests have been selected for MGDI based thresholds development and



Flood prone forests		Fire prone forests	
1a	Pathasila	1b	Rifu
2a	Bura Mayang	2b	Manas*
3a	Pobitora*	3b	Sonai Rupai*
4a	Orang*	4b	Kaliyani
5a	Kamakhya Hills	5b	Langtingmupa
6a	Kukrakata Hills	6b	North Cachar*
7a	Kaziranga*	7b	Barail*
8a	Dihingmukh	8b	Badsahi Tila

Figure 1.
(a) Location of the study area in India (b) flood and fire prone forests.

discrimination of the disturbed areas. The details of the selected forests, i.e. eight for each of flood and forest fire, were shown in **Figure 1**. The flood prone forests were mainly situated along the Brahmaputra River, whereas the fire prone forests were distributed throughout the Assam State.

3. Data used

3.1 Satellite data

The 16-day composite Enhanced Vegetation Index (EVI) data products (MOD13Q1) and 8-day composite Land Surface Temperature (LST) data products (MOD11A2) for the period of 2001 to 2011 were downloaded from the MODIS web-site (www.e4ftl01.cr.usgs.gov/MOLT/). The datasets were re-projected to Geographic (Lat/Long) projection and respective scale factors were applied on the datasets [16]. The 8-day composite LST data was converted to 16-day composite using simple average, as the EVI is available at 16-day interval.

3.2 Forest boundary

The forest boundaries of Assam State were generated by digitizing the Survey of India Topomaps at 1:50,000 scale. According to the World Database on Protected Areas (www.protectedplanet.net) Assam State constitutes total 14 Protected Areas (PA), out of which 7 viz. Pabitora, Orang, Kaziranga, Manas, Sonai-Rupai, North Cachar and Barail, were analyzed in the present study. Theoretically no resource exploitation is allowed in PA's of categories I and II (IUCN, 1994). For further analysis, boundary pixels were excluded to avoid the contamination error.

3.3 Flood inundated area

The date wise flood maps were downloaded from National Remote Sensing Centre (NRSC) web site (www.nrsc.gov.in) prepared by Disaster Management Support Service Group of NRSC/ISRO, Hyderabad. The extent of flood was extracted from each geo-referenced image and stacked at different time scale (annual and multi-year). Flood intensity maps were generated based on the number of flood occurrence in a pixel within a year (**Figure 2**).

3.4 Forest fire data

Date wise forest fire information for Assam State was collected from MODIS site (https://earthdata.nasa.gov/data/near-real-time-data/firms/active-fire-data) for different locations as point information. A grid of 1 × 1 km dimension was created for the entire forest area and total number of forest fire incidents within each grid was recorded at different temporal interval (annual and multi-year) to generate fire intensity grid and subsequent use (**Figure 3**). Major districts where forest fire was reported during the study period include Hailakandi, Cachar, Karbi Anglong, Kamrup, Kokrajhar and NC Hills. The forest fire frequency for each of the selected forests during the study period was given in **Table 1**.

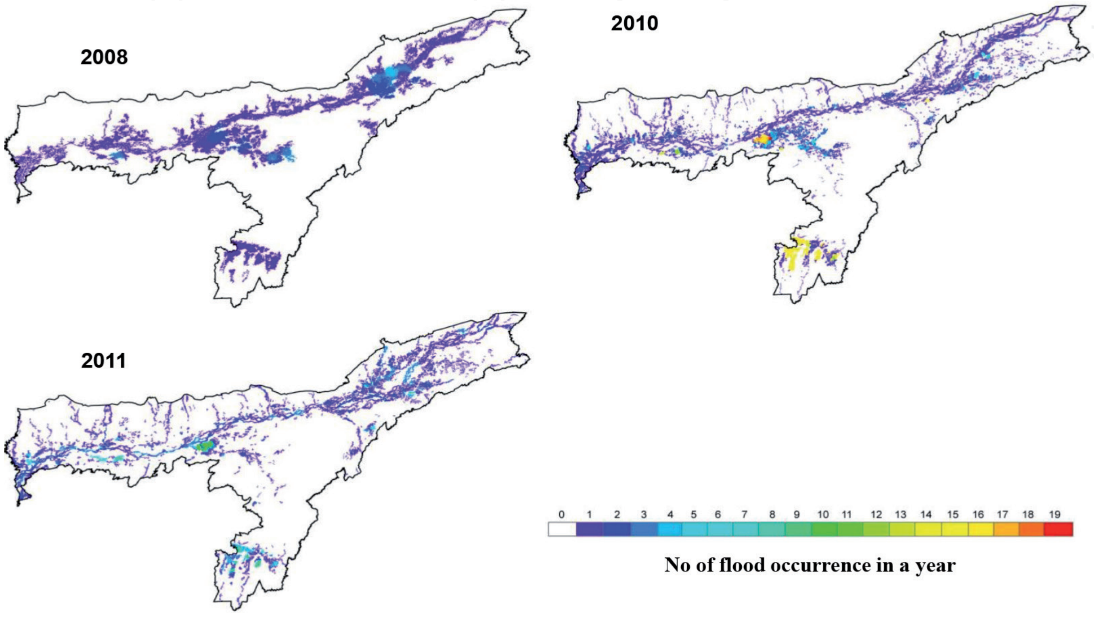


Figure 2.
Flood intensity map of Assam State (www.nrsc.gov.in).

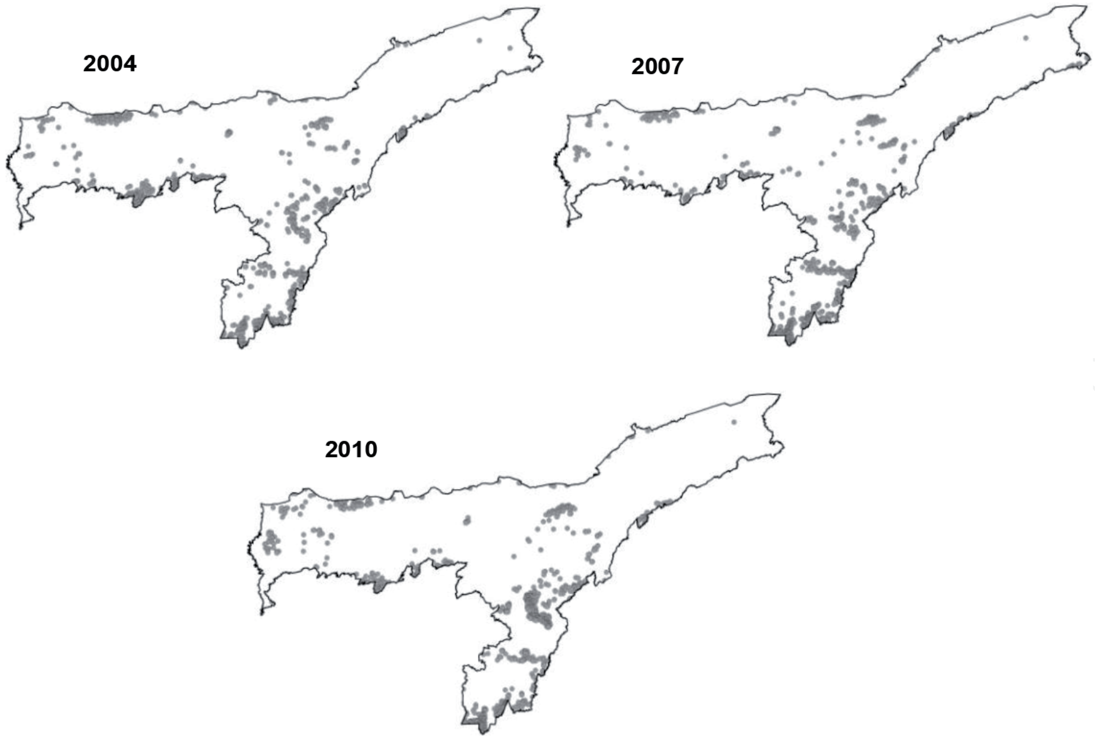


Figure 3.
Forest fire intensity map.

Year	Rifu	Manas	Sonai Rupai	Kaliyani	Langting Mupa	North Cachar	Barail	Badsahitila
2001	15	1	10	0	1	1	2	18
2002	2	23	1	1	2	0	1	16
2003	4	18	18	4	20	19	40	219
2004	12	17	55	5	44	20	26	96
2005	12	6	18	6	64	11	25	86
2006	35	13	32	6	41	31	58	158
2007	6	6	19	12	43	17	45	252
2008	4	4	41	16	25	7	27	108
2009	52	24	54	18	71	33	84	157
2010	11	17	21	4	165	11	41	212
2011	36	23	29	2	64	16	14	91

Table 1.
Forest fire events for selected Assam State forests (2001–2011).

4. Methodology

The MODIS global disturbance index (MGDI) was developed based on the concept that any perceptible disturbance of ecology will result in a significant alteration in vegetation and a concomitant change in the land surface temperature [14, 16].

In the present study, the flood and forest fire were selected as the causative factors that create ecological disturbance to address both the non-instantaneous and instantaneous disturbance, respectively. In case of instantaneous disturbance like forest fire, the disturbance is manifested immediately after the event, resulting in immediate increase in LST with decreased vegetation cover. On the contrary, non-instantaneous disturbance like flood will not trigger immediate change in either LST or EVI due to availability of abundant moisture for evaporation to offset the loss of transpiration. Whereas, in the following year the effect of flood damage was evident due to vegetation mortality and severe structural damage, which will eventually lead to increase in annual maximum LST due to the reduction in transpiration [14].

The instantaneous ($MGDI_{inst}$) and non-instantaneous ($MGDI_{non\text{-}inst}$) MGDI were computed using the following equations:

$$MGDI_{inst} = \frac{\left(LST_{max} / EVI_{max-post}\right)_{current\ year(y)}}{\left(LST_{max} / EVI_{max-post}\right)_{multi-year\ mean(y-1)}} \quad (1)$$

$$MGDI_{non-inst} = \frac{\left(LST_{max} / EVI_{max}\right)_{current\ year(y)}}{\left(LST_{max} / EVI_{max}\right)_{multi-year\ mean(y-1)}} \quad (2)$$

Where, $MGDI_{inst}$ and $MGDI_{non\text{-}inst}$ are the instantaneous and non-instantaneous MGDI value, respectively. LST_{max} and EVI_{max} are the annual maximum 16-day composite LST (°C) and EVI, respectively. $EVI_{max\text{-post}}$ is the maximum 16-day composite EVI following the LST*max*, current year (y) is the year being evaluated for disturbance and multi-year mean (y − 1) is the mean of the ratios excluding the current year [14, 16].

A two-step methodology, as explained by Dutta et al. [16], was adopted for to discriminate the disturbed forest areas caused due to flood and forest fire. In the 1st step, the % change in MGDI values were calculated based on the time-series data for each pixel. Whereas in the second step the MGDI based thresholds were estimated for flood and forest fire, separately. The Percentage change in MGDI for both the instantaneous and non-instantaneous disturbance were calculated using the following equation:

$$\%change\ in\ MGDI_{current\ year(y)} = \frac{MGDI_{current\ year(y)}}{Multi-year\ mean\ MGDI_{(y-1)}} \times 100 \quad (3)$$

As discussed earlier, the forests prone to flood and fire were selected based on the temporal occurrence of the natural disturbance. Total 16 representative forests frequently affected by flood and forest fire were extensively analyzed to develop the thresholds for flood and forest fire separately based upon the % change of MGDI over multi-year mean. The spatio-temporal variation of the % change in $MGDI_{non\text{-}inst}$ over the Assam forest area was shown in **Figure 4** for some selected years.

The year-wise % change in MGDI was generated for all the representative forests wherein only the flood affected pixels were considered. Similarly, year-wise % change in MGDI was generated for the pixels undergone forest fire. The temporal profile of the percent change in MGDI of each forest was compared with the area weighted flood and fire intensity, to confirm the effect of natural disturbances on the MGDI. The multi-year mean value plus one standard deviation of the % change in MGDI was considered to be the threshold, and the value was used for

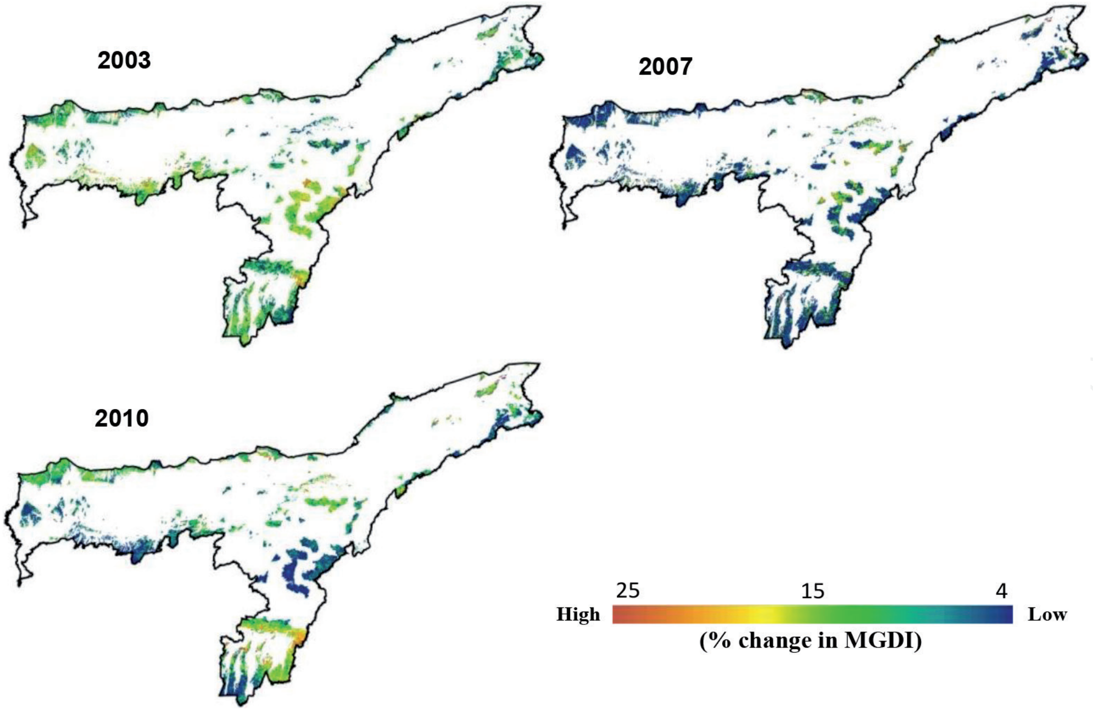


Figure 4.
Percent change in $MGDI_{non\text{-}inst}$ over the Assam forest area.

discrimination of the disturbed pixels [16]. Due to the slow and gradual impact of flood, unlike forest fire, a lower disturbance threshold was estimated in case of flood. The % change of MGDI greater than 7% and 11% of the temporal mean was fixed for discriminating the non-instantaneous (flood) and instantaneous (forest fire) disturbed pixels.

The selected thresholds were applied on the % change MGDI images (both non-instantaneous and instantaneous, separately) for identifying the year-wise disturbed forest areas. The year-wise % disturbed area was estimated for each forest and the temporal profiles were used to analyze the disturbance intensity at spatio-temporal scale. Upon integration of the year-wise disturbed area, disturbance prone maps were generated for both instantaneous and non-instantaneous events.

5. Results and discussion

5.1 Disturbed area caused by the flood

The summary statistics of the flood affected forests is shown in **Table 2**. According to the % disturbed area it was found that the year 2003, 2008, 2009 and 2010 were the most disturbed years caused by river flood in comparison to rest of the years. These findings are in corroboration with the rainfall data collected from Indian Meteorological Department (www.imd.gov.in). During 2001, 2002, 2004, 2005 and 2006, the disturbed area for all the selected forests were less than 10% of the total area, whereas in 2007 and 2011, only few of the selected forests like Pobitora, Orang and Kukrakata Hills could cross the disturbed area limit of 10%. During 2003 the impact of flood was more than 2010 in the forests namely Phathasil, BuraMayang and Orang. On the contrary, in case of Pobitora, Kamakhya Hills, Kukrakata, Kaziranga and Dihing mukh the devastating effect of the 2010 flood was found to supersede the effect of 2003 flood.

The disturbed area maps of the Assam forests showed (**Figure 5**) that the area under disturbance was much higher in the year of 2003, 2008 and 2010 in comparison to others, whereas it was minimum in the year of 2006. The flood intensity maps (**Figure 2**) showed that the extent of flooded area is mainly confined around the Brahmaputra and Barak River valley, but it was interesting to note that a subset of the flood pixels were marked as disturbed pixels (**Figure 5**). Hence, the temporal frequency of flood along with extent was a decisive factor whether a pixel was disturbed or not. For example, in BuraMayang around 80% of the total forest area

Year	Phathasil	Bura Mayang	Pobitora	Orang	Kamakhya Hills	Kukrakata Hills	Kaziranga	Dihing mukh
2001	8.4	1.2	4.7	8.4	6.7	2.0	1.4	1.4
2002	7.4	9.1	8.4	4.3	7.9	2.0	3.4	4.3
2003	39.1	31.2	17.1	10.4	29.6	9.3	4.0	6.1
2004	7.2	5.4	4.0	3.0	7.5	4.1	0.7	1.4
2005	0.5	1.1	0.0	2.6	0.0	0.0	0.3	3.3
2006	0.4	1.5	0.9	3.6	2.5	0.0	0.1	2.9
2007	4.8	8.5	14.0	4.1	8.8	1.1	2.8	5.8
2008	18.9	9.0	2.5	10.0	12.9	17.8	0.9	7.4
2009	28.0	10.2	10.2	12.4	2.5	6.1	2.6	9.4
2010	12.2	24.0	30.1	8.1	34.6	22.8	14.2	20.6
2011	1.9	1.2	0.6	11.8	2.5	11.1	2.0	2.1

Table 2.
Percent disturbed area caused by flood in selected Assam State forests.

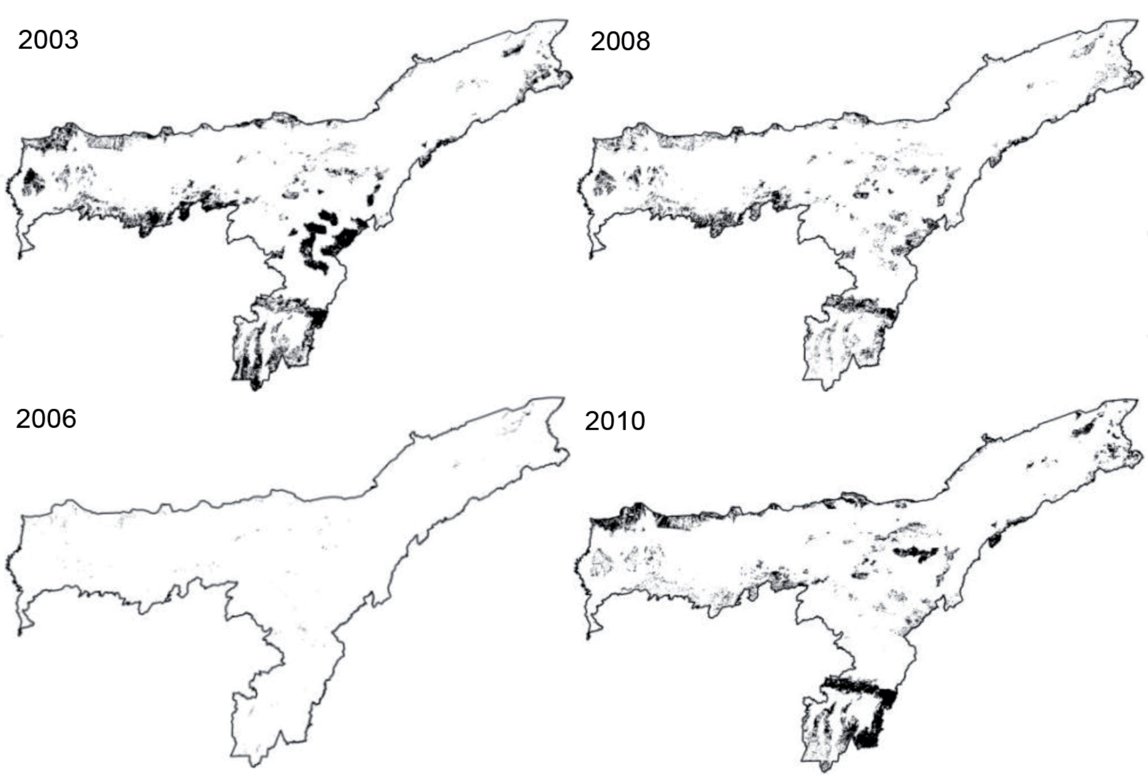


Figure 5.
The disturbed area maps of Assam forests shows higher disturbances in the 2003, 2008 and 2010 and a minimum in 2006.

was under flood during 2008 with frequency value of one, whereas during 2010 around 40% forest area was inundated by flood with frequency more than 10. Consequently, the disturbance was recorded in 9% of the total forest area in 2008, whereas it was around 24% during 2010. Similarly, in case of Pobitora the whole forest was under flood during both 2008 and 2010, but due to the difference in flood frequency the disturbed area were 2.5 and 30.1% of the total area, respectively.

The temporal dynamics of disturbed area, caused by river flood, for two selected forests, namely Kamakhya and Kukrakata Hills was shown in **Figure 6**. In case of Kamakhya Hills the year 2010 was found to the most disturbed year, followed by 2003 and 2008. Hardly any disturbance was noticed during 2005, 2006, 2009 and 2011. Similarly, in case of Kukrakata Hills also three major flood events were observed in 2010, 2008 and 2003. Though the major flood years were common in both the cases, their magnitude varies.

5.2 Disturbed area caused by forest fire

The distribution of disturbed area caused by forest fire is shown in **Table 3**. Unlike flood, the spatial extent of % disturbed area caused by forest fire was much lower as the fire is a localized phenomenon. A maximum value of 3.5% of the total forest area was disturbed due to the fire during 2010 in Barail forest. More than 2% of the forest area was affected in Sonai Rupai, Langting Mupa, Barail and Badsahitila forests during 2003. Whereas in 2010 more than 1% of the total forest area of Sonai Rupai, North Cachar and Barail was affected.

It was noteworthy that unlike flood, forest fire intensity was not in direct corroboration with disturbed area statistics (**Tables 1** and **3**). As discussed earlier, the point locations of forest fire were converted to fire intensity information using 1 km grid, to make it spatially contiguous, as the extent of forest fire information was not available. Hence, the discrepancy between the disturbed area statistics and fire frequency may be attributed to lack of spatial representation of fire extent. In addition frequent fire incidences might have hindered the process of re-generation and vegetative growth of the forest causing insignificant changes in the MGDI values in post incidence dates. For example, in case of Rifu forest the fire frequency was 52 and 36 during 2009 and 2011, respectively, but the disturbed area was 0.34 and 0.45% of the total forest area. On the other hand, 0.84% of the forest area was found to be disturbed during 2010 with only 11 fire incidences. Similar kind of observation was found in case of Badsahitila also, where the fire frequency was

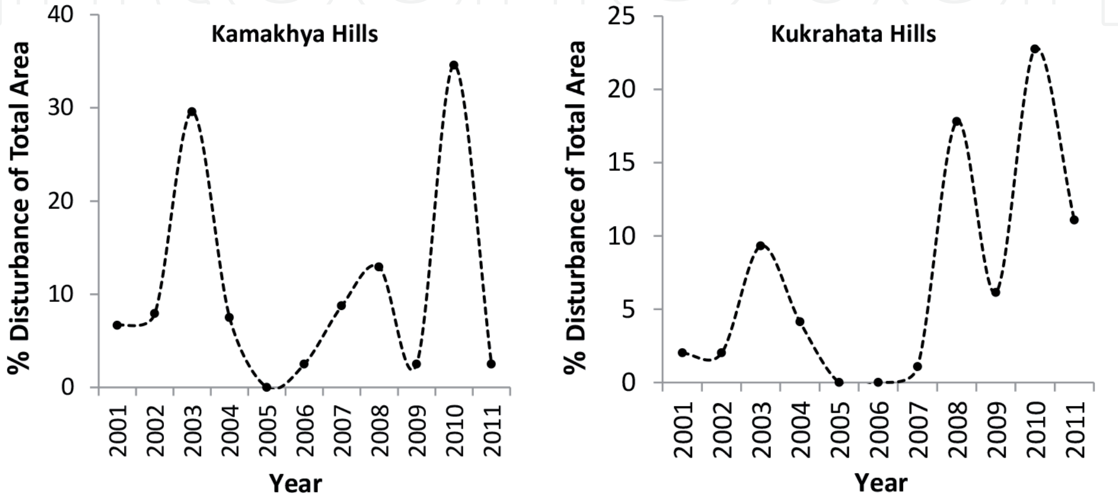


Figure 6.
Temporal dynamics of disturbed area caused by river flood for two selected forests of Assam state.

Year	Rifu	Manas	Sonai Rupai	Kaliyani	Langting Mupa	North Cachar	Barail	Badsahitila
2001	0.18	0.00	0.05	0.00	0.01	0.01	0.00	0.14
2002	0.00	0.00	0.03	0.26	0.18	0.00	0.00	0.12
2003	0.28	0.26	2.11	0.53	1.80	0.98	1.88	3.73
2004	0.24	0.23	0.07	0.13	0.98	0.08	0.07	0.73
2005	0.01	0.01	0.67	0.13	0.15	0.16	0.60	0.34
2006	0.01	0.01	0.00	0.00	0.20	0.11	0.16	0.00
2007	0.00	0.00	0.23	0.39	0.29	0.25	0.48	0.28
2008	0.07	0.08	1.78	0.34	0.26	0.31	0.58	0.05
2009	0.34	0.46	0.46	0.00	0.28	0.31	0.23	1.39
2010	0.84	0.44	1.55	0.05	0.00	1.34	3.44	0.69
2011	0.45	0.17	0.23	0.06	0.06	0.12	0.44	0.11

Table 3.
Year-wise percentage disturbed forest area caused by forest fire for selected forests of Assam State.

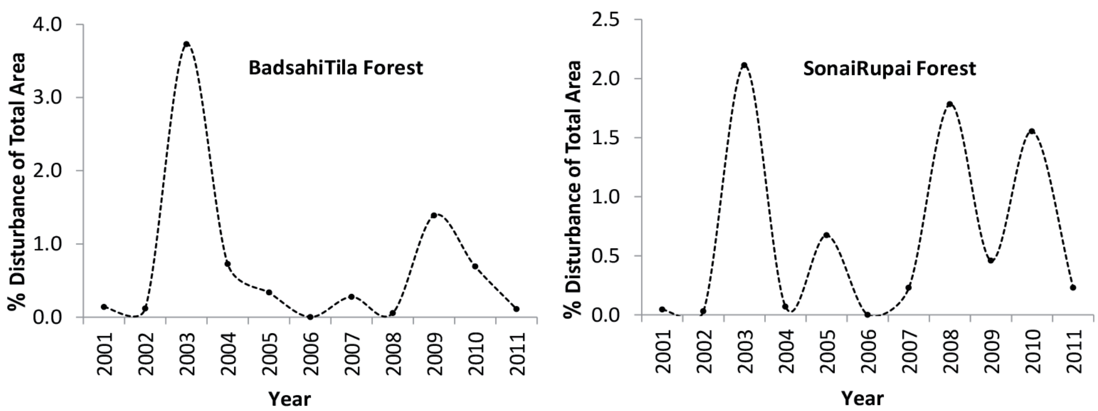


Figure 7.
Temporal dynamics of disturbed area caused by the forest fire for selected forests of Assam state.

more than 150 times during 2003, 2006, 2007, 2008, 2009 and 2010, but the % disturbed area were 3.73, 0.21, 0.28, 0.05, 1.39 and 0.69, respectively.

The temporal dynamics of disturbed area induced by the forest fire for two selected forests, namely Badsahitila and Sonai Rupai, were shown in **Figure 7**. In case of Badsahitila, the major disturbance due to forest fire was found during 2003, followed by the year 2009, whereas during 2001, 2002, 2005, 2006, 2007, 2008 and 2011 very less area was noted to be disturbed due to the fire incidences. On the other hand, in case of Sonai Rupai three major disturbances were noted during 2003, 2008 and 2010, with two other intermediate disturbances during 2005 and 2009. The major fire incidents were reported from moist deciduous forest and grass lands.

5.3 Mapped forest areas prone to disturbance

The spatial distribution of both the non-instantaneous and instantaneous forest disturbances maps have been generated and presented in **Figures 8** and **9** respectively. In non-instantaneous disturbance the effect is not triggered immediately in terms of changes in LST and/or EVI. In contrast post-event effect is immediately exhibited due to changes in LST and EVI, for example, in case of forest fire both the LST increases and the EVI changes drastically. Based upon the percent

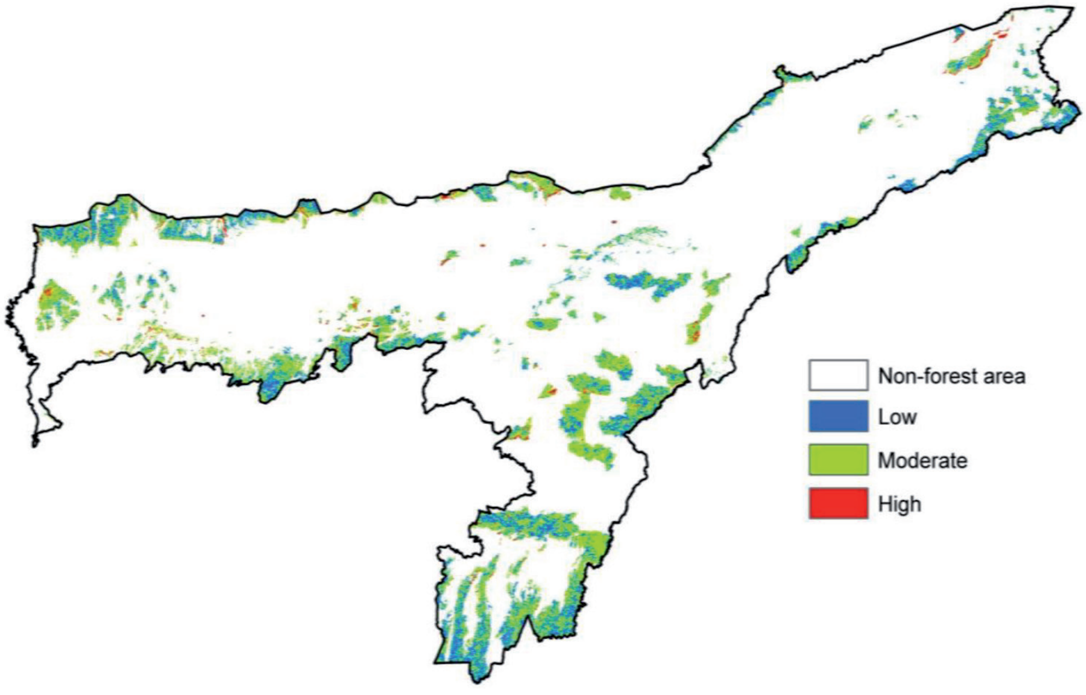


Figure 8.
Spatial distribution of non-instantaneous disturbance categories.

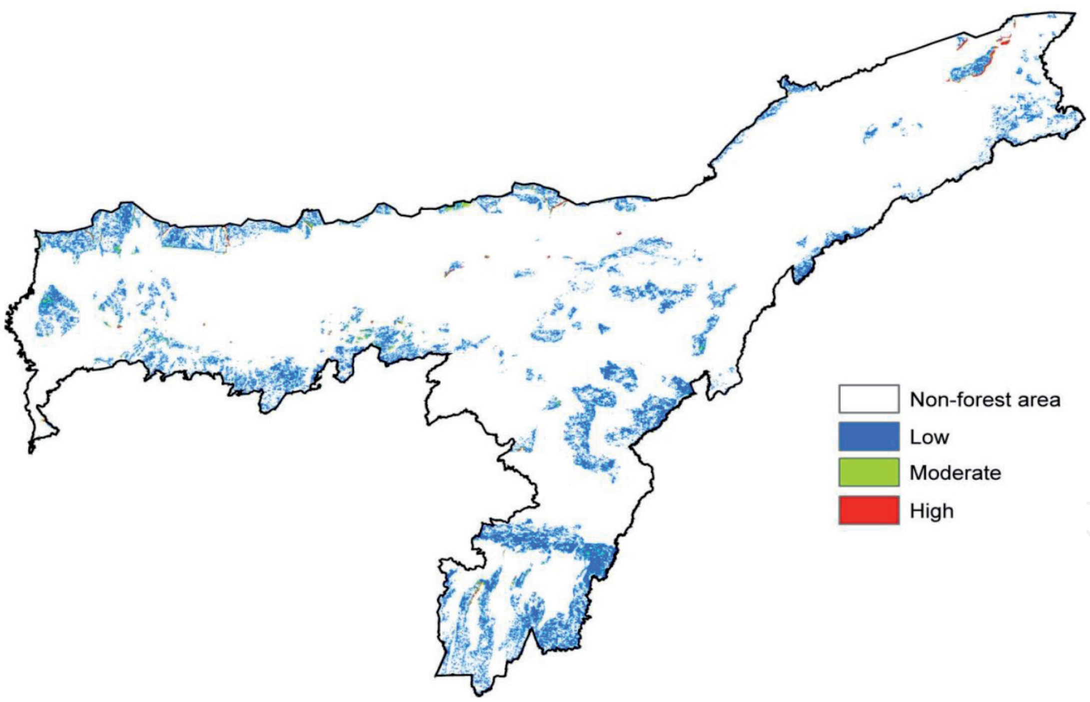


Figure 9.
Spatial distribution of instantaneous disturbance categories.

change of MGDI, both the disturbance types are classified into low, medium and high category to spatially depict the disturbance regime. It was seen that most of the non-instantaneous disturbed area falling under "low" category, followed by "moderate". Patches of "highly disturbed" areas are observed in north of Tinsukia district which falls under the flood plain of Brahmaputra River. Scattered patches of "highly disturbed" areas also noticed along the northern boundary of the Assam state adjoining to Bhutan, Kokrajhar and at the border of Karbi Anglong (East) and Golaghat districts. Under instantaneous disturbance regime most of the forest areas are falling under "low" disturbance category presumably due to high threshold value. Notably the forests of north Tinsukia district falls under “highly disturbed” category in both the instantaneous and non-instantaneous disturbance.

6. Conclusions

The ecological disturbance regime of the Assam forest area was assessed using Global Disturbance Index derived from the time-series MODIS EVI and LST data. The % change in MGDI from its multi-year mean was found to be in good agreement with the flood as well as forest fire intensity. The thresholds for non-instantaneous disturbance, i.e. flood, was found to be lower than the instantaneous disturbance, i.e. forest fire. The time-series disturbed area maps were able to capture the spatio-temporal dynamics of the disturbance regimes. The high disturbed area due to flood were in good agreement with the high rainfall year. The temporal profiles of the forest specific disturbed area could able to distinguish the major disturbed years. The disturbed prone area maps were able to classify the Assam forest areas into three major classes, which can be further utilized for the better management of the forest areas. The main assumption of the study was that the disturbances were created due to two natural hazards, like flood and forest. However, disturbances can be caused by disease/pests, anthropogenic interference, climate change etc. which needs to be examined. Hence, future study can be adopted for estimating the disturbance regime using multiple factors with an intensive ground data support. In the present study, forest fire events was used for estimating the fire intensity, whereas with the aid of the forest fire extent the present methodology would have been more robust. Sensors with better spatial resolution would increase the estimation accuracy of the disturbed area for localized disturbance.

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Conflict of interest

The authors declare no conflict of interest.

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References

[1] Dudley N, Mansourian S, Stolton S, Suksuwan S. 2010. Do protected areas contribute to poverty reduction?. Biodiversity. 2010; 11: 5-7. DOI: 10.1080/14888386.2010.9712658.

[2] Hannah L, Midgley G, Andelman S, Araujo MB, Hughes G, Martiner-Meyer E, Pearson RG, Williams P. Protected area needs in a changing climate. Frontiers in Ecology and Environment. 2007; 5: 131-138. DOI: org/10.1890/1540-9295 (2007)5[131:PANIAC]2.0.CO;2.

[3] Amiro BD, Todd JB, Wotton BM, Logan KA, Flannigan MD, Stocks BJ. Direct carbon emissions from Canadian forest fires, 1959-1999. Canadian Journal of Forest Research, 2001; 31: 512-525.

[4] Canadell JG, Mooney HA, Baldocchi DD, Berry JA, Ehleringer JR, Field CB. Carbon metabolism of the terrestrial biosphere: A multi-technique approach for improving understanding. Ecosystems, 2000; 3: 115-130.

[5] Fraser RH, Li Z, Cihlar J. 2000. Hotspot and NDVI Differencing Synergy (HANDS): A new technique for burned area mapping over boreal forest. Remote Sensing of Environment, 2000; 74: 362-376.

[6] Kurz WA, Stinson G, Rampley GJ, Dymond CC, Neilson ET. 2008. Risk of natural disturbances makes future contribution of Canada's forests to the global carbon cycle highly uncertain. Proceedings of the National Academy of Sciences of the United States of America. 2008; 105: 1551-1555. DOI: 10.1073/pnas.0708133105.

[7] Running SW. 2006. Is global warming causing more, larger wildfires. Science. 2006; 313: 927-928.

[8] Van derWerf GR, Randerson JT, Collatz GJ, Giglio L, Kasibhatla PS, Arellano AF Jr. Continental-scale partitioning of fire emissions during the 1997 to 2001 El Niño/La Niña period. Science. 2004; 303: 73-76. DOI: 10.1126/science.1090753.

[9] Picket STA, White PS (Editors) The Ecology of Natural Disturbance as Patch Dynamics. London/Orlando, FL, USA: Academic Press; 1985. 472 p. ISBN 0-12-554520-7.

[10] Tilman D. The resource-ratio hypothesis of plant succession. American Naturalist. 1985; 125(6): 827-852.

[11] Alcaraz-Segur D, Paruelo JM, Cabello S 2009. Baseline characterization of major Iberian vegetation types based on the NDVI dynamics. Plant Ecology. 2009; 202: 13-29. DOI: 10.1007/s11258-008-9555-2.

[12] Kinyajui MJ. NDVI based vegetation monitoring in man forest complex, Kenya. African Journal of Ecology. 2011; 49: 165-174. DOI. org/10.1111/j.1365-2028.2010.01251.x.

[13] Kerr JT, Ostrovsky M. 2003. From space to species: ecological applications of remote sensing. Trends in Ecology and Evolution. 2003; 18, 6: 299-305.

[14] Mildrexler DJ, Zhao M, Running SW. Testing a MODIS Global Disturbance Index across North America. Remote Sensing of Environment. 2009; 113: 2103-2117. DOI:10.1016/j.rse.2009.05.016.

[15] Nemani RR, Running SW. Estimation of regional surface resistance to evapotranspiration from NDVI and Thermal-IR AVHRR data. Journal of Applied Meteorology. 1989; 28: 276-284. DOI: org/10.1175/1520-0450(1989)028<0276:EORSRT>2.0.CO;2.

[16] Dutta D, Das PK, Paul S, Sharma JR and Dadhwal VK. Assessment of ecological disturbance in the mangrove forest of Sundarbans caused by cyclones using MODIS time-series data (2001-2011), Natural Hazards. 2015; 79(2): 775-790. DOI 10.1007/s11069-015-1872-x.