

Forest cover monitoring and prediction in a Lesser Himalayan elephant landscape

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We have monitored the forest cover depletion in parts of Assam and Arunachal Pradesh over an area of 42,375 km² in an elephant landscape falling in the Lesser Himalaya, North East India and report the results here. The US Army topographic maps (1924) and multi-date satellite images (1975, 1990, 2000 and 2009) were visually interpreted on-screen for post-classification comparison and forest cover change detection. The exercise showed continuous high loss of forest cover during the study period. A land area having 17,846.27 km² forest in 1924 was depleted to 12,514.56 km² by 1975, 11,861.75 km² by 1990, 10,808.92 km² by 2000 and 10,256.58 km² by 2009, thereby indicating a constant decrease in forest cover by 12.59%, 1.54%, 2.48% and 1.31% respectively. The total loss in forest cover was estimated to be about 7590 km² from 1924 to 2009. The Cellular Automata Markov Model has predicted a further likely decrease of 9007.14 km² by 2028. In general, more districts of Assam than Arunachal Pradesh and more plains than hills faced deforestation. We have identified increasing human population and subsequent demand on the land for cultivation as major reasons for forest cover depletion.

Keywords: Change detection, deforestation, elephant landscape, North East India, satellite images.

SHIFTING cultivation and modern agriculture are the major drivers of deforestation globally. Deforestation was patchy before the Europeans colonized the world¹. Beginning in the late 18th century, industrial development exacerbated the pressure on forests for wood. Consequently, 15% of the world's forests was deforested². Much of the forest clearing took place in the tropical regions¹, which continues even today. Forests provide a multitude of important services³. Burgeoning growth of the human population and resultant rapid destruction of forests for agriculture, infrastructure and industrial development have been immensely detrimental to the world ecology and economy. Forest depletion is responsible for the loss of species habitat and the biodiversity throughout the earth⁴. Deforestation also adds to global warming and climate change⁵. Hence, continuous forest cover monitor-

ing using modern tools is imperative to understand the cause-and-effect scenario of the global forests.

According to a study conducted using remote sensing, India lost 28% of forest cover between 1930 and 2013 (ref. 6). Puyravaud *et al.*⁷ estimated a high rate of forest decline, i.e. 0.8–3.5% per year in India, though the rate has slowed down of late⁶. Forest and biodiversity depletion still persists in the country, with the highest rate in Assam, North East (NE) India. The Bodo ethnic community in Assam resorted to large-scale deforestation after 1990, since their demand for a separate state was not met for long time. Srivastava *et al.*⁸ reported 232.19 km² forest loss in Sonitpur district, Assam, alone between 1994 and 2001. Later, Kushwaha and Hazarika⁹ revealed a loss of 344 km² forest area in Kameng and Sonitpur Elephant Reserves (including Sonitpur district and parts of adjoining districts) between 1994 and 2002. These two studies reported higher than the national average deforestation in Sonitpur district. Chartier *et al.*¹⁰ found that man–elephant conflicts have exacerbated in Sonitpur from the early 80s onward because of the human occupation of erstwhile elephant habitats in the district. Asian elephants, with a large home range and food requirements, have been severely affected by habitat degradation, fragmentation, forest depletion and ultimate loss of corridors^{11,12}, and consequent human–elephant conflicts¹³.

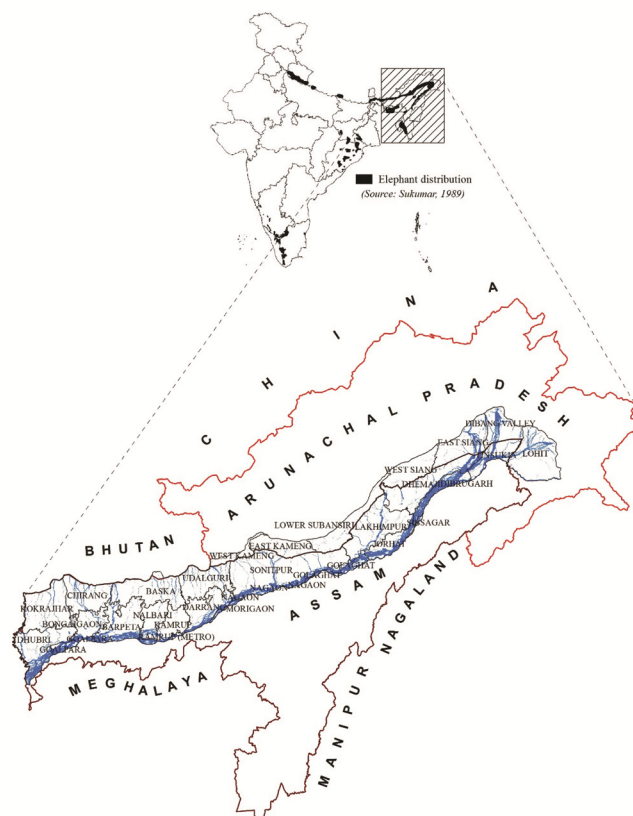


Figure 1. Location of the study area in the Lesser Himalaya, North East India.

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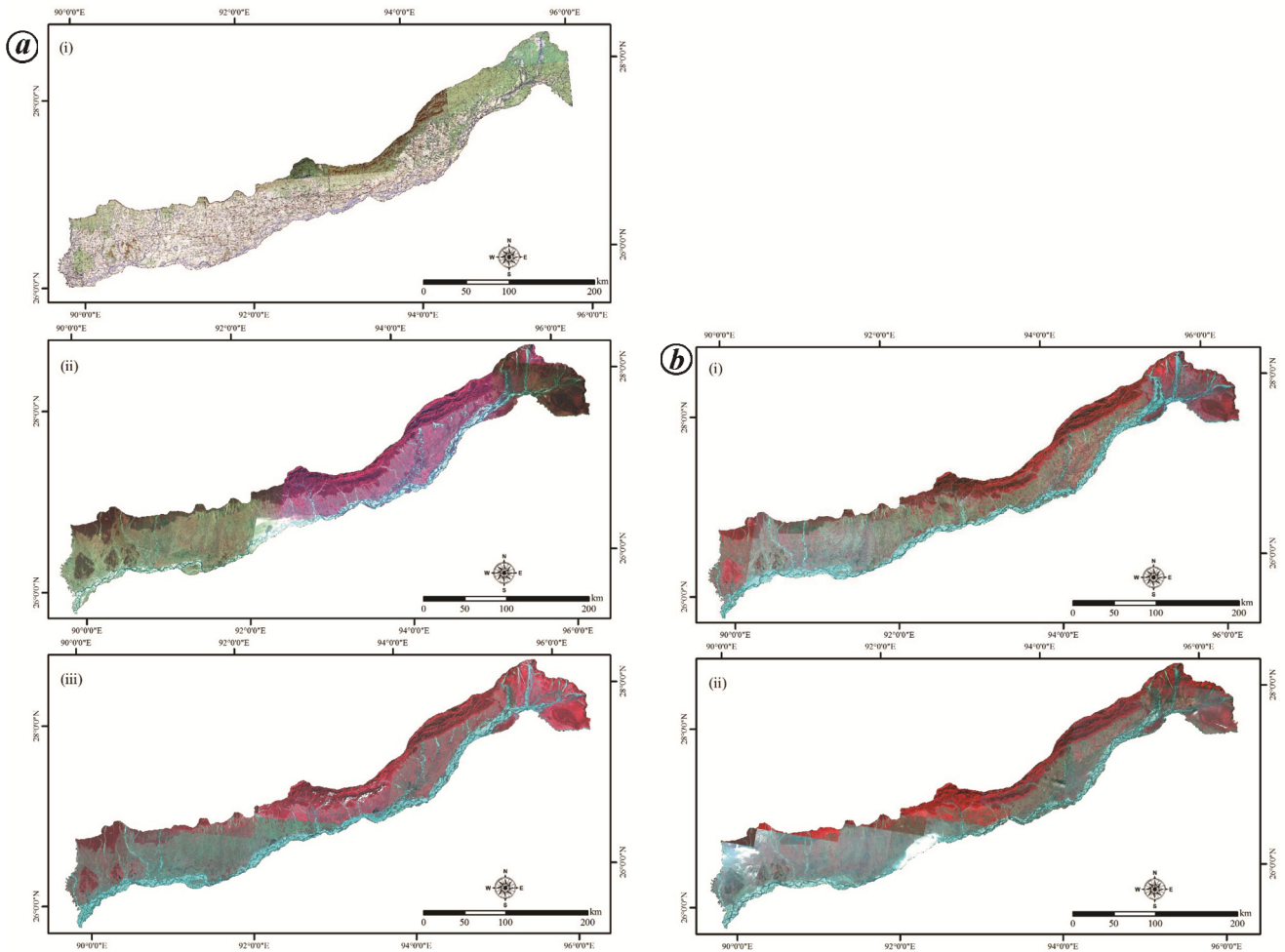


Figure 2. a, (i) Topographic map (1924), and false colour composite (FCC) of (ii) Landsat MSS (1975) and (iii) Landsat TM (1990). b, FCC of (i) IRS LISS-III (2000) and (ii) IRS LISS-III (2009).

Table 1. Area under different vegetation types/land uses during 1924 to 2028 through 1975, 1990, 2000 and 2009

Vegetation type/land use	Area (km ²)					
	1924	1975	1990	2000	2009	2028 (predicted)
Subtropical evergreen dense		2,245.32	2,238.62	2,221.65	2,214.87	2,165.93
Subtropical evergreen open		430.94	419.94	405.89	392.59	366.83
Tropical wet evergreen dense		1,576.56	1,530.29	1,455.79	1,429.39	1,346.39
Tropical wet evergreen open		389.71	434.36	389.76	300.04	218.89
Tropical semi-evergreen dense	17,846.27	1,607.61	1,537.57	1,511.69	1,456.73	1,361.94
Tropical semi-evergreen open		294.22	333.25	346.29	359.29	409.78
Moist deciduous dense		3,780.93	3,226.32	2,733.68	2,249.72	1,579.17
Moist deciduous open		1,389.56	1,378.18	1,037.06	1,135.49	884.06
Sal dense		357.28	280.49	210.56	166.62	99.76
Sal open		98.30	131.91	129.05	115.21	86.52
Riverain		59.96	59.95	59.95	58.77	56.19
Bamboo		284.16	290.86	307.54	377.87	431.67
Scrub	261.68	750.79	782.02	508.55	525.09	399.08
Tea garden	773.65	652.22	690.95	710.49	713.97	720.54
Non-forest	21,086.04	21,722.21	22,279.62	23,583.09	24,250.27	25,772.28
River	2,330.66	6,630.43	6,630.77	6,630.76	6,495.90	6,342.86
Settlement	76.70	104.79	129.90	133.19	133.19	133.09
Total	42,375.00	42,375.00	42,375.00	42,375.00	42,375.00	42,375.00

Such conflicts have significantly increased over time. Geospatial technology has been used effectively in the past for forest cover dynamics^{6,14,15} and wildlife habitat^{16,17} studies in India.

The present study was undertaken to monitor and predict the ever-continuing deforestation in one of the India's most important elephant habitats extending over an area of 42,375 km² comprising parts of Assam and Arunachal Pradesh (up to 1000 m elevation) in the Lesser Himalaya, NE India. Cellular Automata Markov Model (CAMM) was employed to predict the land cover for a future period, as CAMM performs better in spatio-temporal domain¹⁸. As elephants are long-ranging animals and are distributed across the landscape, it is important to carry out the study covering large areas to address the habitat status over time, which can be used for effective habitat conservation.

The study area covered a vast elephant landscape of 42,375 km² along the West Bengal–Assam, Assam–Bhutan, Assam–Arunachal Pradesh borders in the Lesser Himalaya, NE India (25°44'46"–28°20'01"N and 89°42'00"–96°24'21"E) (Figure 1) and encompassed two biogeographic zones¹⁹, viz. Himalaya and North-East and the Himalaya biodiversity hotspot. Singh and Kushwaha²⁰ reported nearly 75% encroachment-related vegetation loss in the Himalaya biodiversity hotspot. Large number of tea gardens are located across the study area. It also harbours evergreen, semi-evergreen, moist deciduous, sal and khair–sissoo forests²¹ and includes parts of three elephant ranges and six elephant reserves²². A report by the Ministry of Environment and Forests, Government of India has addressed the area as an 'elephant landscape'²³. With the highest rate of deforestation in India, the study area can also be addressed as the 'deforestation hotspot of India'. Tiwari *et al.*²⁴ have referred to Sonitpur district as a 'ground zero' for human–elephant conflicts. With an estimated elephant population of 10,139, NE India is considered as one of the largest strongholds of the Asian elephant²⁵.

The US Army topographic maps (USATM) of 1924 on 1 : 250,000 scale together with multi-date Landsat MSS, TM, IRS LISS-III images pertaining to 1975, 1990, 2000 and 2009 respectively, were used to monitor forest cover over an 85-year period (Figure 2 *a* and *b*). Using 2000–2009 period forest change and CAMM, forest cover for the year 2028 was predicted. The satellite image processing included dark pixel subtraction-based radiometric correction²⁶, followed by geometric correction of IRS LISS-III images employing ortho-rectified Landsat images. Histogram matching was carried out for preparing image mosaic for the entire study area, followed by visual on-screen interpretation for mapping the intended forest and non-forest categories. Image mosaic was then used for forest types and canopy density (10–40% = open and >40% = dense forest) mapping. The USATM facilitated in the mapping of forest cover only. Interim map

prepared from the satellite image mosaic of 2009 was field-checked from 5 to 20 March 2009 (optimal season for the study area) for interpretation and accuracy assessment.

The vector layers of vegetation types/land uses were generated from the satellite image of 2009 in the beginning. These layers were used with satellite image mosaics of the preceding periods, i.e. 1975 and 1990 for mapping of the change areas. A total of 489 field points was ground-visited using Trimble Juno-SB GPS receiver and Survey of India topographic maps. The geo-coordinates of all the points, encompassing forest types, canopy density and land use categories were recorded. This was followed by post-field interpretation and rectification of the maps using 250 field points. The remaining 239 points were used for mapping accuracy assessment. Forest cover change was worked out through post-classification comparison, while the annual rate of change was estimated using Puyravaud's²⁷ formula

$$\text{Forest cover change (\%)} = \left[\frac{1}{(t_2 - t_1)} \times \ln \left(\frac{A_2}{A_1} \right) \right] \times 100,$$

where $(t_2 - t_1)$ is the period analysed, and A_1 and A_2 represent forest area at time t_1 and t_2 respectively.

Forest cover prediction for 2028 was made using 1990 and 2009 forest vector layers in CAMM with a 5 × 5 contiguity filter. The chi-square (χ^2) test for goodness of fit was applied to test the potential of the model.

Satellite images facilitated in the mapping of all forest types in the study area²¹. We achieved a classification accuracy of 86.75% for the 2009 map, which implies that the accuracy of the satellite image-based maps for the other two periods was also high. Both dense and open categories of the seven forest types, viz. subtropical evergreen, tropical wet evergreen, tropical semi-evergreen, moist deciduous, sal, riverine and bamboo forests, and five non-forest categories, viz. scrub, tea garden, non-forest, river and settlement could be mapped for all periods (Figure 3 *a* and *b*). Geospatial analysis showed extensive loss of forest cover and a very high rate of deforestation from 1924 to 2009 (Table 1). Forest cover in 1924 was 17,846.27 km², which depleted to 12,514.56 km² by 1975, 11,861.75 km² by 1990, 10,808.92 km² by 2000, and 10,256.58 km² by 2009, thereby showing progressive decrease by 12.59%, 1.54%, 2.48% and 1.31% respectively (Figure 4). A forest cover depletion of 17.92% was seen from 1924 to 2009. The predicted forest cover for 2028 was found to be 9007.14 km², showing a further decrease by 2.94%. Conversely, the non-forest area increased by 17.92% during the period 1924–2009.

There was 0.64% mean annual rate of forest depletion in the study area from 1924 to 2009 (85 years); the highest (0.93%) and lowest (0.36%) was during 1990–2000

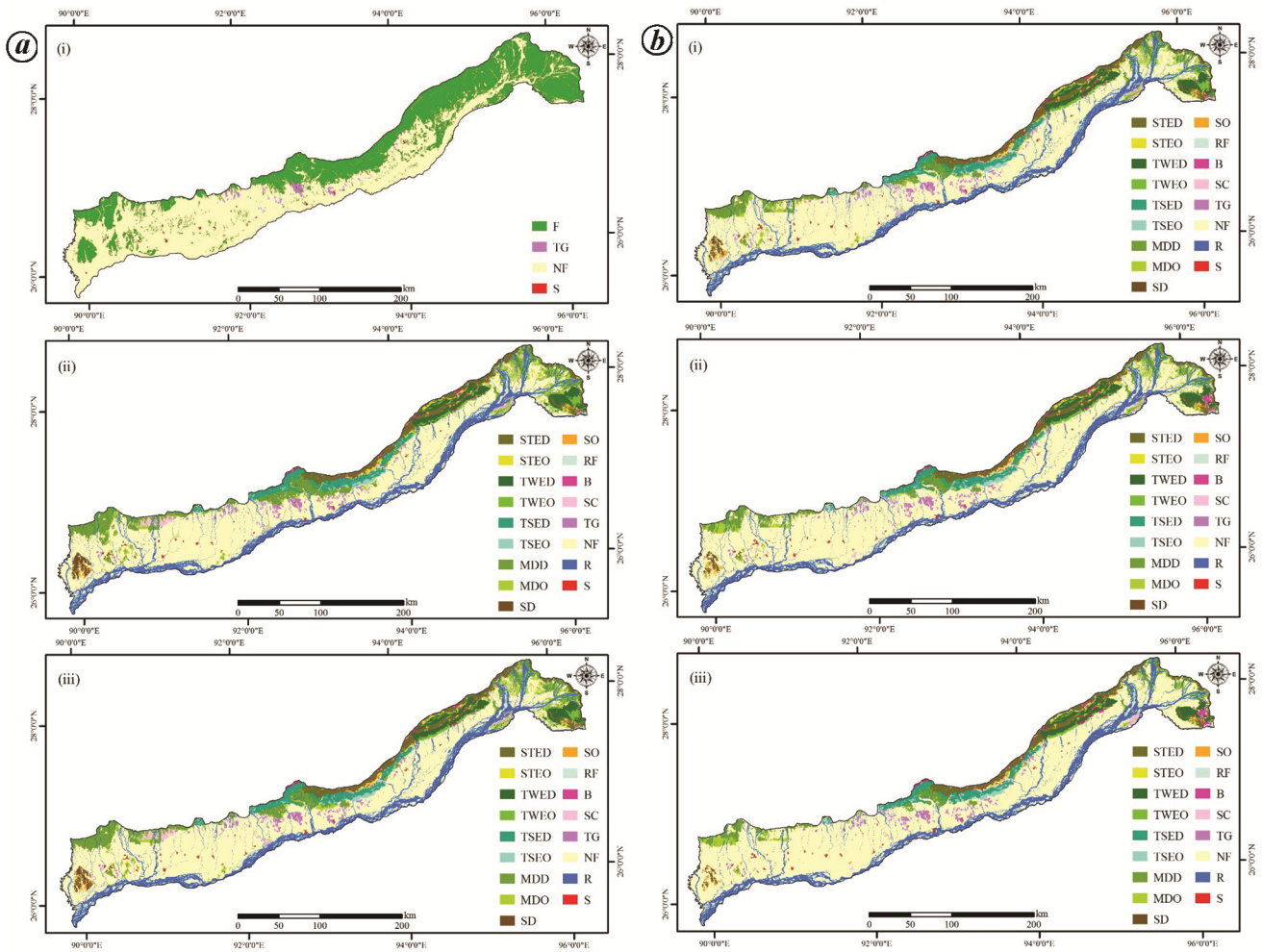


Figure 3. a, Forest type/land use map of (i) 1924, (ii) 1975 and (iii) 1990. [STED, Subtropical evergreen dense; STEO, Subtropical evergreen open; TWED, Tropical wet evergreen dense; TWEO, Tropical wet evergreen open; TSED, Tropical semi-evergreen dense; TSEO, Tropical semi-evergreen open; MDD, Moist deciduous dense; MDO, Moist deciduous open; SD, Sal dense; SO, Sal open; RF, Riverain forest; B, Bamboo; SC, Scrub; TG, Tea garden; NF, Non-forest; R, River and S, Settlement]. b, Forest type/land use map of (i) 2000, (ii) 2009 and (iii) 2028 (predicted).

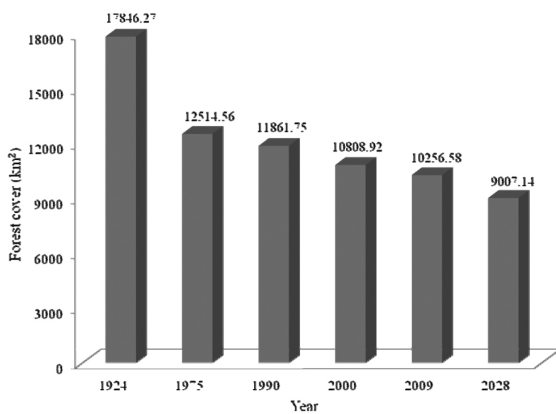


Figure 4. Forest cover during 1924–2028.

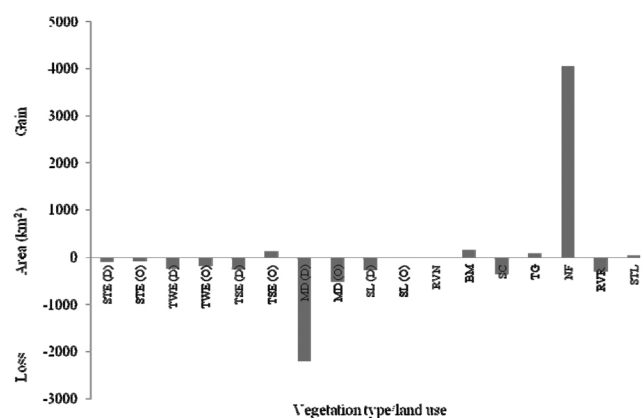


Figure 5. Gain/loss of forest type/land use during 1975–2009.

and 1975–1990 respectively. Nearly 7590 km² forest cover was depleted in 85 years, while another 1249.44 km² forest cover is predicted to be lost by 2028. Comparatively,

the annual rate of deforestation was higher in Assam than in Arunachal Pradesh, primarily due to inhospitable mountainous terrain in the latter¹⁴. Among the districts in

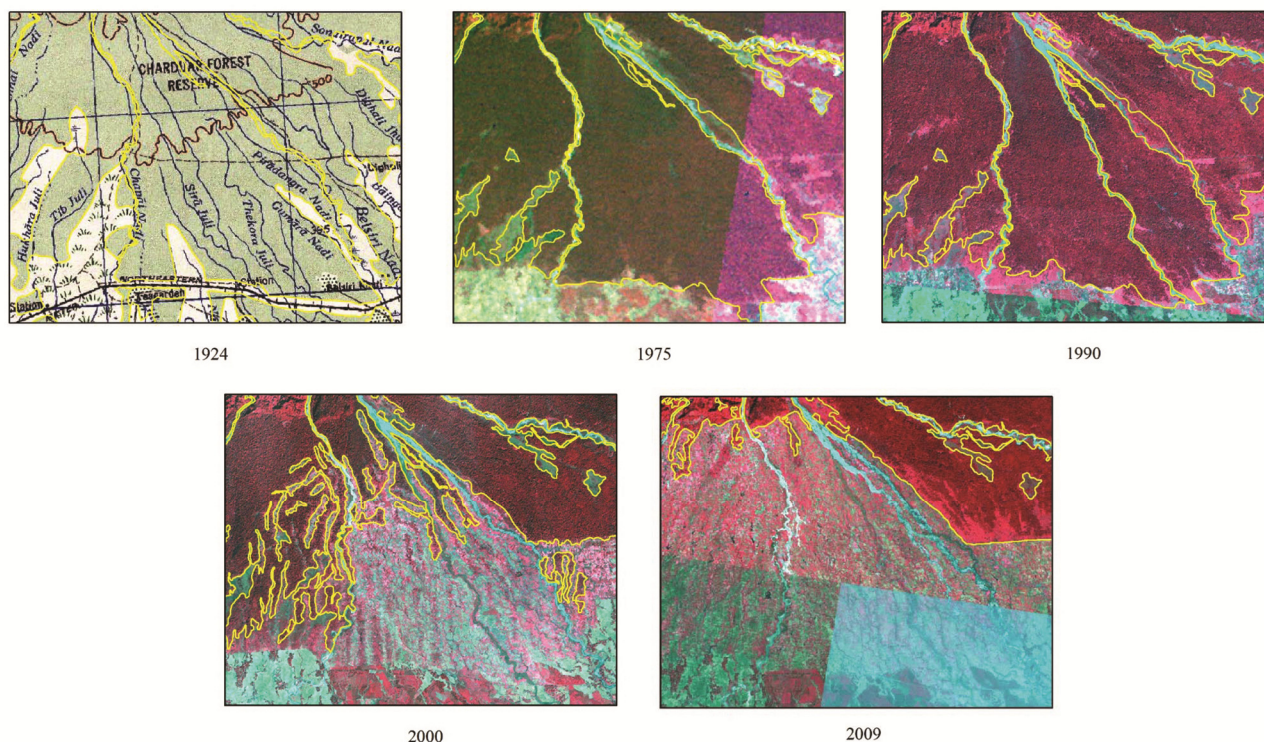


Figure 6. Large-scale deforestation in Charduar Reserve Forest, Assam during 1924–2009 (yellow line indicates forest boundary).

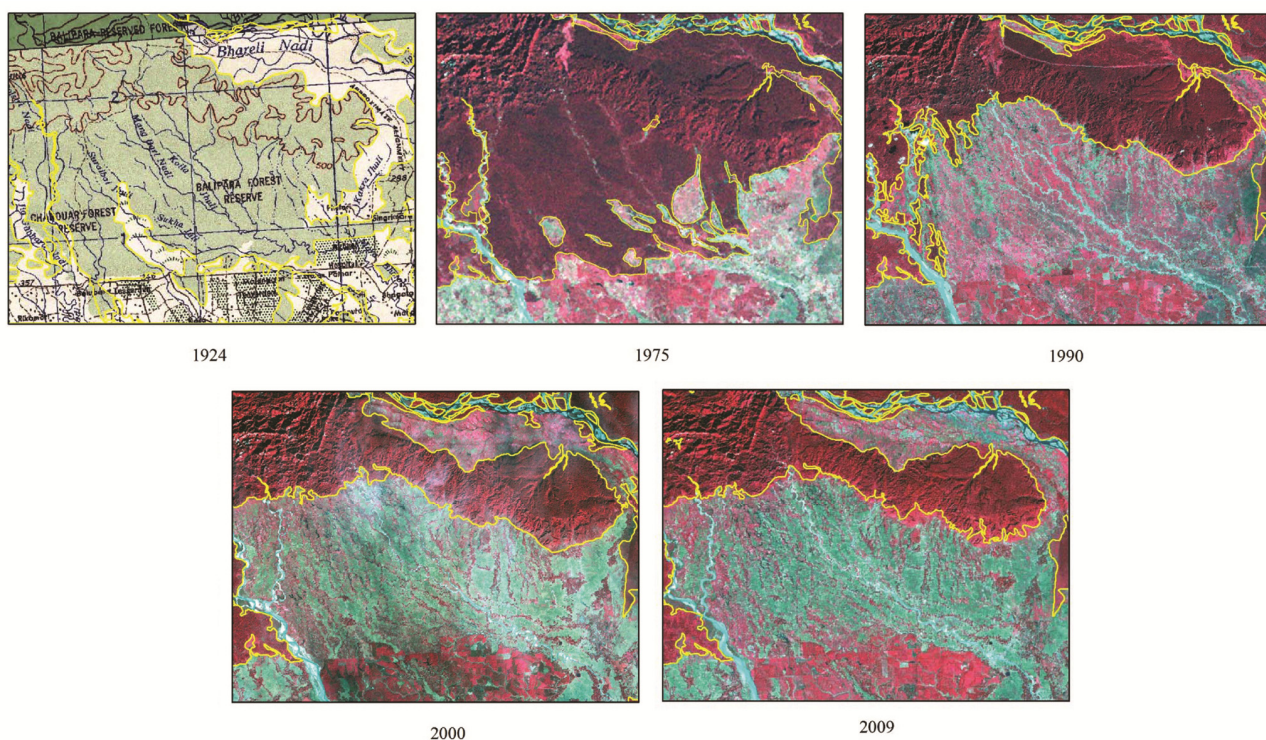


Figure 7. Large-scale deforestation in Balipara Reserve Forest, Assam during 1924–2009 (yellow line indicates forest boundary).

Assam, highest deforestation was noticed in Barpeta (5.31%), followed by Dhemaji (2.91%), Tinsukia (2.40%), Lakhimpur (2.01%), Darrang (1.95%), Dibrugarh (1.78%) and Sonitpur (1.19%) during the 85-year

study period. Area-wise, the largest amount of forest cover loss was noticed in Dhemaji (1419.99 km²), followed by Sonitpur (825.85 km²), Lohit (in Arunachal Pradesh) (820.61 km²), Tinsukia (662.28 km²) and Lakhimpur

(635.15 km²). This study highlights the worst-affected districts as far as deforestation is concerned. The overall state of deforestation matches well with that reported by Srivastava *et al.*⁸ and, Kushwaha and Hazarika⁹. Pandit *et al.*²⁸ have reported a decrease in forest cover in the same region from 75,790 km² (in 1970) to 70,300 km² (in 2000), with a further projected decrease to 54,790 km² in 2100 and a deforestation rate of 0.25%.

In this study, moist deciduous dense forest suffered the highest loss of 1531.21 km², followed by moist deciduous open (254.07 km²), sal dense (190.66 km²), tropical semi-evergreen dense (150.88 km²) and tropical wet evergreen dense (147.17 km²) forest between 1975 and 2009 (Figure 5). It has been predicted that an area equivalent to 670.55 km² of moist deciduous dense forest would deplete further by 2028. If the same rate of deforestation continues, it is expected that moist deciduous open, sal dense, tropical semi-evergreen dense and tropical wet evergreen dense will deplete further by 251.43, 66.86, 94.78 and 82.99 km² respectively. In the non-forest categories, loss in scrub area was 225.70 km². The bamboo area expanded by 93.70 km² between 1975 and 2009 due to opening up of the forests. The area under tea gardens also increased during the study period. Other non-forest categories too showed progressive increase in area in time and space, and a further increase is expected by 2028. CAMM predicted the forest cover change well at 95% confidence ($\chi^2_{17}(0.05) = 41666.3, P < 0.000$).

This USATM and satellite image-based study assessed deforestation in a Lesser Himalayan elephant landscape in NE India and reported alarming, continuous loss of forests from 1924 to 2009. It has also predicted further depletion of the forests, mainly moist deciduous category, abutting agricultural areas. In general, higher deforestation was noticed in the upper Assam districts than in the districts of Arunachal Pradesh. Large-scale deforestation was observed in Dhemaji, Sonitpur, Tinsukia and Lakhimpur districts of Assam, and Lohit and East Siang districts of Arunachal Pradesh. Manas Tiger Reserve, Sonai-Rupai Wildlife Sanctuary, Charduar (Figure 6), Balipara (Figure 7), Nowduar, Biswanath and Behali Reserve Forests suffered maximum loss. The Gohpur Reserve Forest has suffered complete deforestation. Large-scale decline of forests has progressively diminished flora and fauna alike. Deforestation and loss of wildlife habitat in upper Assam is likely to influence not only the adjoining Bhutan and Arunachal Pradesh, but also lower Assam so far as the wildlife and ecosystems are concerned. Therefore, forests need to be restored to their original status for long-term survival of humans and wildlife. This study has demonstrated the potential of geospatial technology and CAMM in forest cover monitoring and prediction.

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***Bt*-cotton–vegetable-based intercropping systems as influenced by crop establishment method and planting geometry of *Bt*-cotton in Indo-Gangetic plains region**

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The present study was conducted at ICAR-Indian Agricultural Research Institute, New Delhi in a split-plot design replicated thrice with four main-plot treatments, i.e. four combinations of two cotton establishment methods (CEMs) and two planting geometries (PGMs) [M_1 – transplanted cotton (90 × 60 cm PGM); M_2 – transplanted cotton (120 × 45 cm PGM); M_3 – direct seeded cotton (DSC; 90 × 60 cm PGM); M_4 – DSC (120 × 45 cm PGM)]; while sub-plot treatments comprised three intercropping systems [S-Ct – sole cotton; Ct + Ok – cotton + okra (1 : 2 row ratio); Ct + Cp – cotton + cowpea (vegetable purpose; 1 : 2

row ratio)]. It can be inferred from the study that transplanted cotton (TPC) with 90 × 60 cm planting geometry in *Bt*-cotton + vegetable cowpea intercropping system exhibited maximum seed-cotton equivalent yield (SCEY) as well as gross and net returns and other economic indices, followed by Ct + Ok and sole cotton. DSC with 90 × 60 cm PGM in Ct + Ok intercropping system proved superior in terms of SCEY, and gross and net returns besides other economic indices. Based upon yield advantage indices, TPC in 90 × 60 cm PGM under Ct+Cp intercropping system and DSC in 90 × 60 cm PGM under both intercrops were found to be the best options. Crop competition indices also revealed that the inclusion of these intercrops is advantageous because of spatial and temporal complementarity, different rooting pattern and plant architecture to utilize natural resources more efficiently in *Bt*-cotton-based intercropping systems in the semi-arid Indo-Gangetic plains region.

Keywords: *Bt*-cotton, crop establishment methods, intercropping systems, planting geometry, vegetable cowpea.

GLOBALLY, cotton (*Gossypium* sp.) is an important commercial crop with India having the largest world acreage of 11.98 M ha, representing about one quarter of global area (35 M ha) under cotton¹. The average productivity of cotton lint in India is far below the world average of 767 kg/ha, and it contributes only to 25% of global production of 26 million tonnes. In north India, cotton is grown in about 1.36 million ha area with a total production of 5.8 million bale and an average lint yield of 722 kg/ha. However, the cotton productivity and profitability are low despite 100% irrigated area, probably due to poor crop establishment and non-standardization of suitable intercrops. Intercropping is one of the highly promising approaches for enhancing agricultural productivity and profitability². Similarly, crop establishment is another most important factor deciding crop performance in sustaining cotton productivity and profitability. At present, farmers are facing problems of shrinking land-holding size, degradation of natural resources, climatic vulnerabilities and low monetary returns due to escalating cost of cultivation and inefficient utilization of agro-inputs³. Thus, production per unit area of land, time and inputs needs to be improved by efficiently harvesting the solar energy and carbon dioxide for conversion into economic produce⁴. As *Bt*-cotton is a short-stature crop of relatively longer duration, its slow initial growth and wider spacing offer vast scope for cultivation of suitable legumes and vegetables as intercrops. Further, improvements in productivity and profitability of *Bt*-cotton-based cropping systems are possible through efficient agronomic management and crop diversification/intensification by intercrops.

At present, no information is available on the inclusion of vegetable intercrops under different crop establishment

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