CURRENT STATUS AND FUTURE PROSPECTS OF MAPPING RUBBER PLANTATIONS IN INDIA

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Present study utilized earth observation satellite data to map acreage of existing natural rubber plantations in India to develop a geo-spatial decision support system for the NR plantation sector in the country. Indian and foreign satellite data were used in the study. Multi-resolution and multi-temporal satellite data were acquired according to phenology of rubber trees for delineation, mapping and estimation of the spatial extent of NR plantations. Standard visual interpretation, satellite data classification, on-screen vectorization, extensive ground truth, survey data of NR area statistics, *etc.* were followed to complete the study. Results found that satellite-derived acreage of NR plantations of age three years and above in the country was estimated to be around 7,22,440 ha. The spatial extent of NR plantations estimated was the highest in the state of Kerala (5,58,600 ha) followed by Tripura (76,954 ha), Karnataka (31,232 ha) and Assam (30,804 ha). Traditional NR growing regions contributed 77 per cent of the total NR plantations in the country, followed by North-eastern states (18%) and Konkan region (5%). Multi-spectral satellite sensors used in this study (both Indian and foreign) were found effective for mapping NR plantations' age three years and above at different scale. Spatial distribution maps of NR were geo-spatially analysed and different useful scientific outcomes were generated. Remote sensing based acreage of NR plantations, scientific uses of geo-referenced NR area distribution maps and necessity of updating the mapping of NR plantations in the country (using latest satellite data) are discussed. Use of geo-spatial technology for mapping entire NR plantations in the whole country was a first attempt in India and it is a powerful tool to monitor changes in the NR plantation landscape of the country in time and space.

Key words: NR acreage, NR plantations, Remote sensing, Satellite data, Spectral reflectance

INTRODUCTION

In India, traditionally natural rubber (NR) (*Hevea brasiliensis*) is cultivated in Kerala and Kanyakumari district of Tamil Nadu (RRSC and RRII, 2012). The other places where rubber is cultivated in the country are North-eastern states, Konkan region of Karnataka, Goa, Maharashtra, parts of Eastern states like Andhra Pradesh, Odisha, West Bengal and Andaman & Nicobar Islands. Traditional area produces 90 per cent of NR in the country but the recent trend showed that NR cultivation was fast expanding in the Konkan region of Karnataka and North-eastern states of India (Pradeep *et al.*, 2015; RRSC and RRII, 2012). Demand for NR is expected to go up in coming years and expanding NR cultivation is urgently needed to meet the rising demand. Hence, it is important to support

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sustainable rubber production to meet the domestic demand. Satellite-based mapping and estimation of acreage of existing NR plantations in the country was carried out to develop a geo-spatial decision support system for monitoring changes in the NR plantation landscapes of the country.

Earth observation satellite data are widely accepted in agriculture crop monitoring, statistics, estimation of production and one of the key tools for monitoring the changes happening on earth (Chong *et al.*, 2017; Krishna *et al.*, 2014; Navalagund *et al.*, 2007; Reddy *et al.*, 2016; Trisurat *et al.*, 2000; Wu *et al.*, 2015). Global Agricultural Monitoring (GEOGLAM) is a global initiative to produce accurate forecasts of agricultural production at national and global scales through the use of satellite data and ground-based observations. In India, crop acreage was monitored using satellite data since 1970s and it is operational in crops like rice, wheat, cotton, jute, mustard *etc.* (Ray and Neetu, 2017). Forecasting Agricultural output using Space, Agro-meteorology and Land based observations (FASAL) and Coordinated programme on Horticulture Assessment and Management using geo-informatics (CHAMAN) are typical examples of use of geospatial technology in agriculture sector by Government of India. It is important to get information on existing acreage of a particular crop to formulate policies and programmes. Thus, remote sensing satellite data is a viable technology to achieve this and satellite-driven output is strong geo-spatial information for analysing and displaying spatial data.

Due to socio-economic reasons and rising demand, NR cultivation has been steadily increasing in the world. Its mapping was explored at various scales in different parts of the world (Chen *et al.*, 2016; Dibs *et al.*, 2017; Dong *et al.*, 2013; Li and Fox, 2011; Razak *et al.*, 2018). Map of entire existing NR cultivation in the whole country was not developed till, however, a few studies were done to map NR plantations in different parts of the country (RRSC and RRII, 2012; Meti *et al.*, 2016). Statistics of NR acreage collected from field surveys which is time consuming, expensive and laborious and lacks spatial information on rubber distribution. Today satellite data is obtainable at different spatial and temporal scales. Thus precise mapping of entire NR cultivation at the national level would help planners and policy makers to get a correct NR distribution map which will be a useful GIS (Geographic Information System) based decision making tool for managing NR plantations in the country. In this study, we have analyzed Indian and foreign satellite data covering NR growing states in the country to develop spatial distribution maps and acreage of NR plantations. The study also focussed on scientific utilities of NR distribution maps and future prospects of using advanced remote sensing technologies to monitor changes in NR plantations in the country.

Study area, data preparation and analysis

All NR growing states in India were selected for the study. Traditional NR growing region of Kerala and Kanyakumari district of Tamil Nadu, Konkan area of Karnataka, Goa and Maharashtra, North-eastern states such as Tripura, Assam, Meghalaya, Nagaland, Manipur, Mizoram, Arunachal Pradesh and other states like Andhra Pradesh, Odisha West Bengal and Andaman & Nicobar Islands were selected to map NR cultivation. Multi-temporal and multi-resolution satellite data were used in the study to estimate the acreage of NR plantations. Because of the deciduous

phenomenon, rubber trees shed leaves during December - January seasons (defoliation) and completely refoliate during March and April (refoliation). Cloud-free satellite data of NR growing regions in the country were acquired according to the phenological stages of NR plantations during March and April (Table 1). Spectral reflectance properties of rubber trees and other dominant species of vegetation were analysed to separate the spectral uniqueness of rubber tree. Both medium and high-resolution satellite data were utilized for the present study. IRS LISS III (23.5m), LISS IV (5.8m), Cartosat PAN (2.5m), Sentinel 2A/2B MSI (10m) and Landsat 8 OLI (30m) were used to develop NR plantation distribution map (Table 1). Data preparation, image fusion, mosaicking, clipping, image enhancements, standard visual interpretation, classification, on-screen vectorization, ground truth *etc.* were done to estimate the acreage of NR (Meti *et al*., 2016; Pradeep *et al*., 2015; RRSC and RRII, 2012).

GPS aided extensive ground survey was conducted across the NR growing states in India and collected information on NR plantation distribution. Before ground truth, detailed information on NR growing Districts/Taluks/Panchayats was collected from Regional Offices of the Rubber Board located all over India. Around 12000 GPS positions were randomly collected by recording latitude and longitude positions from NR holdings across the country and these points have been used for detailed verification of NR distribution maps from satellite data (Fig. 3c). Initially the work was carried out collaborating with Regional Remote Sensing Centre-South (RRSC-S), Indian Space Research Organization (ISRO) to standardize the methodology of delineation of NR plantations using high resolution satellite data (Carto merged LISS IV).

Natural rubber area distribution maps were further subjected to various geo-spatial analyses for generating different outcomes that are relevant for the NR plantation sector. Agricultural drought assessment, terrain characterization, monitoring spatio-temporal changes, Rubber Soil Information System (RubSIS)-an online platform for soil fertilizer recommendation of NR plantations, estimation of the extent of NR plantations for skipping fertilizer application *etc.* were studied by integrating spatial distribution maps of NR (Rubber Board, 2017; Pradeep *et al.*, 2015; Shebin *et al.*, 2014).

Phenological characteristics of NR plantations in satellite data

Natural rubber plantations were clearly segregated from other vegetation using multi-spectral satellite images (Fig. 1). Due to the deciduous phenomenon of NR trees, it shed leaves during December and January seasons and it refoliates fully from February to March and sometimes it extends to April month (Fig. 2a-b). During this season, NR holdings show a unique spectral reflectance of red color in the near infrared band (0.77-

Table 1. **Details of satellite data used for mapping natural rubber plantations in the country**

Satellite data	Sensor and spatial resolution	Year of satellite data
IRS Resourcesat I&II	LISS III - 23.5m, LISS IV - 5.8m	2012, 2013, 2010 to 2012
Cartosat	PAN -2.5m	2010 to 2012
Landsat 8	OLI - 30m	2014 to 2018
Sentinel 2A/2B	MSI - 10m	2018

0.86 μm) of satellite image. Natural rubber holdings looks like bright red patches in optical satellite data. Patches of NR holdings get clearer when the spatial resolution of satellite data increases (Fig. 1a-1e). Natural rubber patches showed low NDVI during December-January seasons due to leaf fall. Most of its values fall between 0.2 and 0.4 NDVI during this period. After complete refoliation, NDVI was high (0.4-0.68) due to thick foliage (Fig. 2c-d). Generally, NDVI represents proxy for vegetation cover, greenness, phenology *etc.* (Yin *et al.,* 2012). On the other hand NR plantations have low NDVI value during December to January due to wintering mediated refoliation (RRSC and RRII, 2012; Razak *et al.,* 2018; Li and Fox, 2011).

Mostly NR plantations of age less than three years old don't have fully developed canopy. In traditional areas these categories have intercrops such as pineapple, plantain, cover crops *etc*. Hence, NR plantations age less than three years age in satellite data showed mixed spectral reflectance of intercrops, soil and other vegetation which leads to spectral complexity (Fig. 3a). But after fully developed canopy the holdings has typical spectral reflectance (Fig. 3a&b). Normally NR plantations of age three years or less are not picked up in medium resolution satellite data (RRII and ATMA, 2014; RRSC and RRII, 2012). It showed greyish color in the satellite images (Fig. 3a). High resolution satellite data (10m or less) supplemented by field information could be used to map these categories of NR holdings. From the study, it was found that many factors to be considered for interpretation and mapping of NR plantations using optical satellite data such as refoliation period of rubber trees and selection of satellite pass, age of NR holdings, intercropping and spatial resolution of satellite data.

Satellite-derived acreage of NR plantations in India

Acreage of NR plantations (age three years and above) in the whole country estimated through remote sensing satellite data was about 7,22,440 ha (Table 2 and Fig. 4). As per this estimate traditional NR growing region has a share of 77 per cent of rubber area whereas North-eastern states together accounted for 18 per cent, Konkan region 5 per cent and eastern coast 0.2 per cent. Remote sensing based NR area was compared with the survey statistics of the Rubber Board for the corresponding period and age and it was found that the variation was only 19,028 ha (2.6%). From field experience, it was evident that spatial resolutions of satellite data, mixed spectral reflectance from surrounding vegetation, scattered nature of NR holdings, terrain conditions of NR cultivation and stage of refoliation of rubber trees influence the mapping of NR plantations. Medium resolution satellite data (IRS LISS III and Landsat 8 OLI,) are preferably suitable for mapping NR plantations at scale 1:50,000. High resolution satellite data (IRS LISS IV and Cartosat PAN merged data) are the best suitable for mapping NR plantations at 1:10,000 scale. But the cost and manpower required are relatively high for using these data at national level. The mapping accuracy of NR plantations was about 86.9 per cent using medium resolution satellite data whereas high resolution satellite data produced an accuracy of about 96.1 per cent. Satellite-derived estimate of NR acreage of different regions in India is briefly discussed below.

Traditional NR growing region

Satellite-derived acreage of NR plantations in the traditional region of Kerala

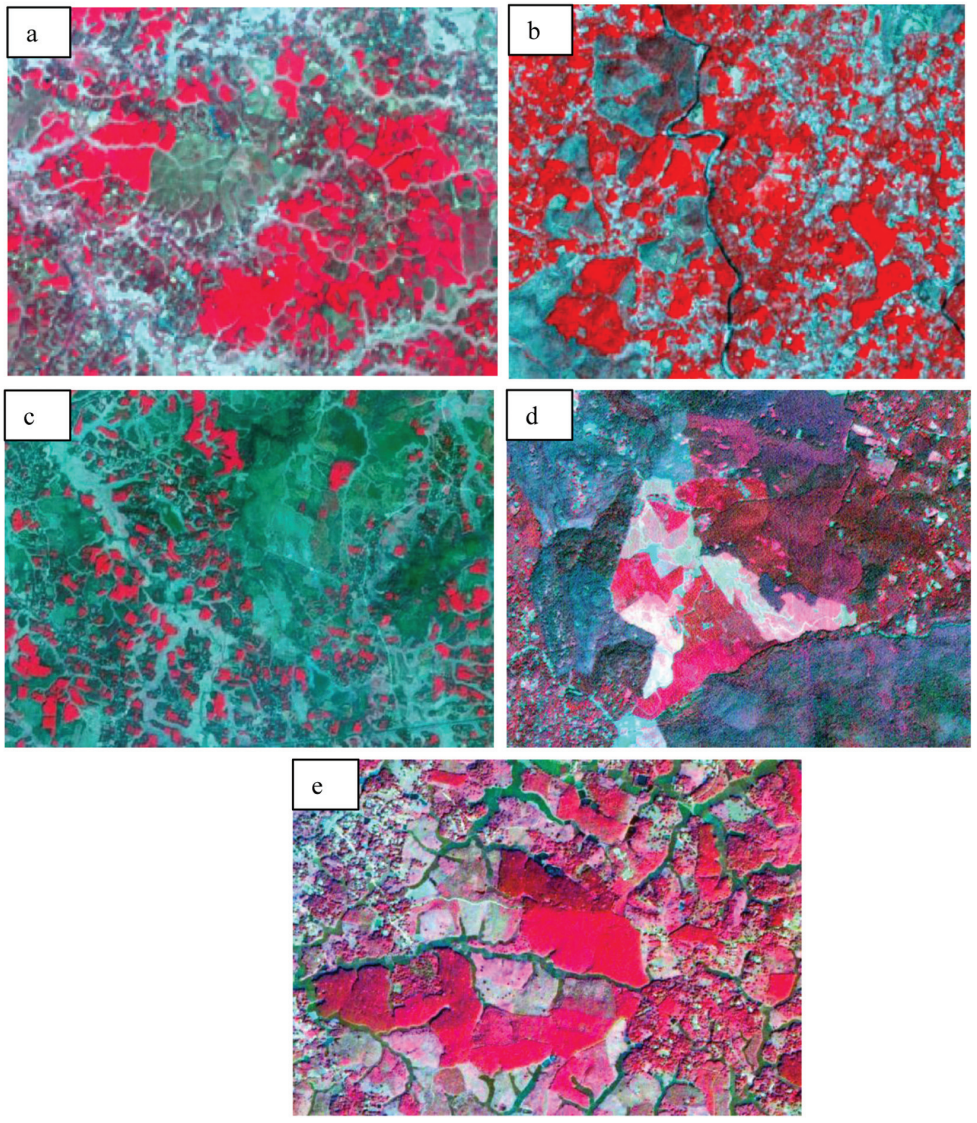

Fig. 1. Rubber plantations in different satellite data a) Landsat 8 OLI (30m), b) IRS LISS III (23.5m), c) Sentinel 2 MSI (10m), d) LISS IV (5.8m) and e) LISS IV merged Cartosat PAN (2.5m). NR appears like bright red colour in optical satellite data. Patches of rubber plantations get more clear when the spatial resolution of satellite data increases (a to e).

and Kanyakumari district of Tamil Nadu estimated was about 5,58,600 ha (Table 2). Natural rubber is cultivated in all districts of Kerala but the spatial extent of NR area was the highest in Kottayam district of Kerala (1,10,724 ha). The least extent of NR cultivation was estimated from Alappuzha (6,792 ha) and Wayandu districts (7,567 ha). Natural rubber cultivation accounted for nearly 13 per cent of the total geographical

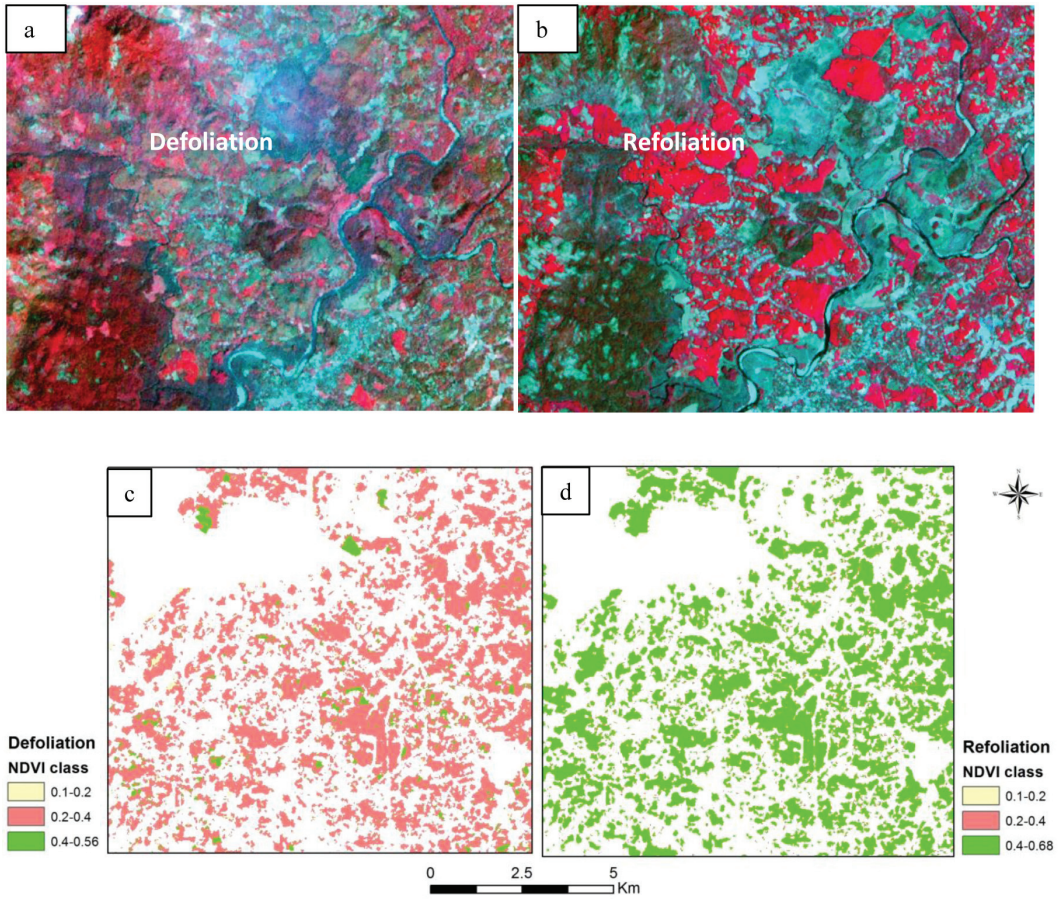

Fig. 2. IRS LISS III satellite data showing defoliation (December- January) and refoliation (March-April) of rubber plantations (2a&b). Normalized Difference Vegetation Index (NDVI) of NR plantations (part of the study area) after defoliation and refolitaion period (2c&d). NDVI values are low when defoliation occurs due to leaf fall and it reached to high when fresh leaves comes during refoliation

extent of Kerala state. Kanyakumari district is the only state in Tamil Nadu where NR is being cultivated in large scale (21,948 ha). Around 5,19,909 ha of the area under NR was estimated from the traditional region using older satellite data as of 2005-2006 (Meti *et al.*, 2016). It indicated that about 38,691 ha of NR area has expanded in the traditional region in between the period 2005 and 2012 (Table 3). Therefore, timely updating of mapping and estimation of NR acreage is relevant to find the spatio-temporal changes in NR cultivation in the traditional region.

North-eastern states

Natural rubber cultivation has been expanding in North-eastern states especially in Tripura and Assam for the last two decades. North-eastern states combinedly

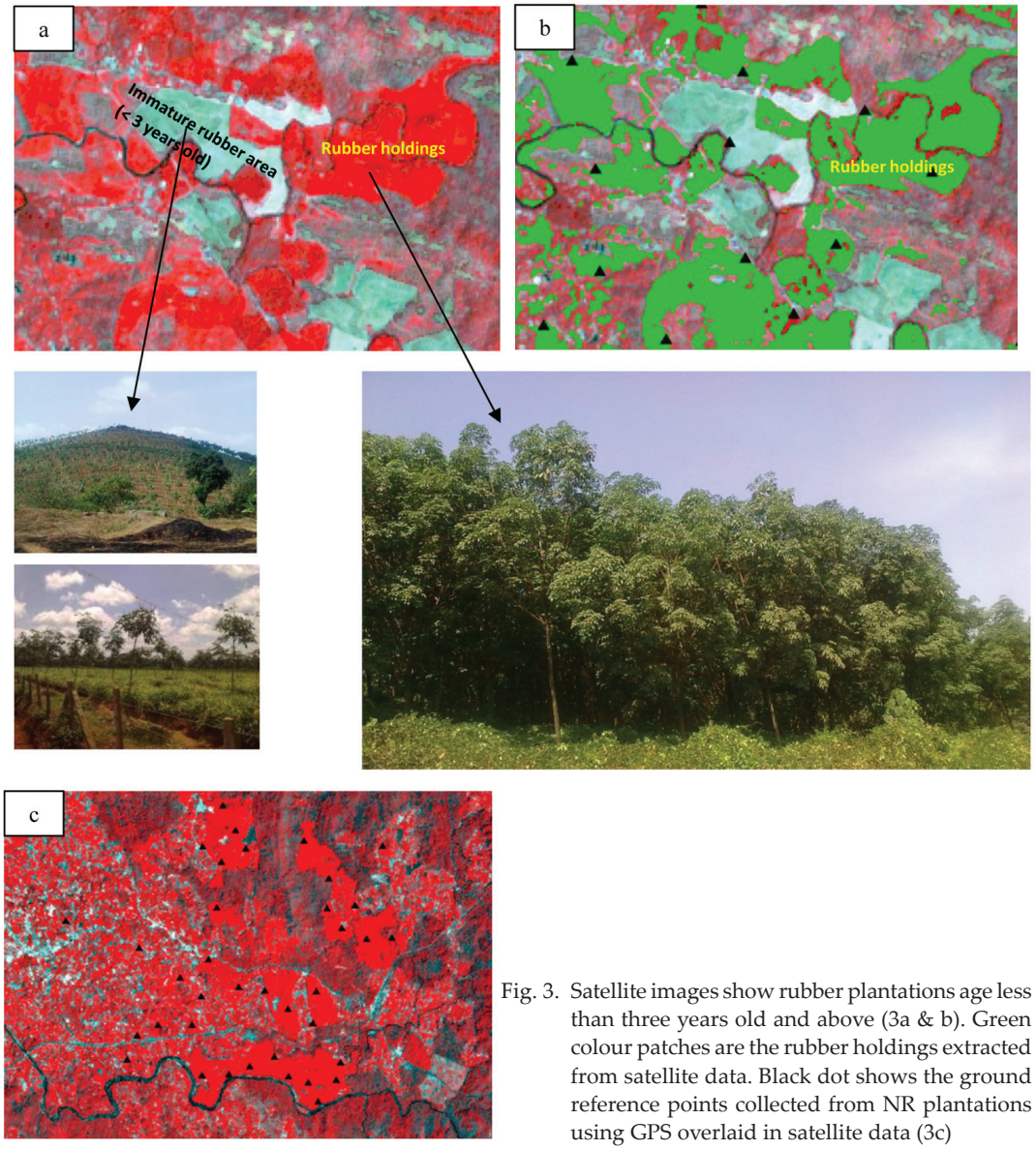

Fig. 3. Satellite images show rubber plantations age less than three years old and above (3a & b). Green colour patches are the rubber holdings extracted from satellite data. Black dot shows the ground reference points collected from NR plantations using GPS overlaid in satellite data (3c)

are the second largest NR producing region in the country. Remote sensing based extent of NR cultivation in Tripura estimated to be around 76,954 ha (as of 2018) whereas an estimate done in Tripura in 2012 found 48,037 ha which were 28,917 ha lower than the present estimate (Table 3). Tripura state witnessed fast expansion of NR cultivation after 2012. Satellite-derived acreage of NR in Assam as of 2011-2012 was 16,872 ha. This area extended to about 30,804 ha in 2018 (Table 3). Natural rubber cultivation has well

established in all districts of Tripura whereas its cultivation in Assam was expanding mainly in the districts of Goalpara, Karbi-Anglong, Karimkhanj and Kamrup. Meghalaya and Nagaland had a considerable extent of NR area but other states like Mizoram, Manipur and Arunachal Pradesh had only meagre extent of NR (Table 2). All these states in North-East India together accounted for 1,29,092 ha of NR which contributed nearly one-fifth area of total area cultivated in the traditional region. It is important to monitor the trend and pattern of expansion of NR cultivation in North-East India.

Table 2. **Satellite-based acreage of natural rubber plantations**

State/District	Acreage of rubber (ha)	Year of satellite data used
Traditional area		
Kerala	536652	2012, 2013
Kanyakumari district (TN)	21948	2013
Konkan region		
Karnataka	31232	2013
Goa	424	2013
Maharashtra	1133	2013
North-eastern states		
Tripura	76954	2018, 2015
Assam	30804	2018
Meghalaya	7950	2015
Nagaland	10730	2017
Mizoram	874	2017
Manipur	1062	2017
Arunachal Pradesh	718	2016
Other states		
Andhra Pradesh	239	2014
Odisha	560	2014
West Bengal	250	2016
Andaman & Nicobar Islands	910	2014
TOTAL		722440

Satellite based mapping is for plantations of age three years and above estimated from different states in India. Survey statistics for the corresponding period recorded total area of about 7,41,468 ha (age three years and above) and the variation accounted is 19, 028 ha (2.6%)

Konkan region

Agro-climatic condition of Karnataka, Goa and Maharashtra (particularly lower foothills of Western Ghats in the Konkan region) are suitable for NR cultivation. Konkan districts of Karnataka *viz.* Dakshin Kannada, Udupi, Coorg, Chikamagalur and Shimoga have a large extents of NR cultivation. Natural rubber acreage based on remote sensing in Karnataka was estimated at about 31,232 ha (Table 2). Earlier estimation of NR area in this state as of 2009-2010 satellite data was 20,972 ha which showed an addition of 10,260 ha of area between the period 2010 and 2013 (Table 3). Scanty and small pockets of areas in Goa and Maharashtra showed NR cultivation (Table 2). Ground truth revealed that NR cultivation was expanding in Maharashtra especially in Sindhudurg district. It is important to update NR acreage of Karnataka because area under young NR holdings (age less than three years) in the state was expanding fast. Almost five per cent of NR cultivation in the country was from the Konkan region of Karnataka, Goa and Maharashtra.

Other states and Union territory

The extent of NR plantations was less across Eastern coastal states of India (Table 2). Natural Rubber plantations were scattered in Andhra Pradesh (East Godavary district), Odisha (Mayurbanj, Baleshwar, Cuttuk, Gajapathi and Dhenkanal districts), West Bengal (Jalpaiguri, Alipurduar and

Table 3. **Satellite-based spatio-temporal expansion of natural rubber plantations**

State	NR area (ha) and year	NR area (ha) and year	Extent of expansion (ha)
Kerala & Kanyakumari dist (TN)	5,19,909 (2005-2006)	5,58,600 (2012-2013)	38,691
Karnataka	20,972 (2009-2010)	31,232 (2013)	10,260
Tripura	48,037 (2011-2012)	76,954 (2018, 2015)	28,917
Assam	16,872 (2011-2012)	30,804 (2018)	13,932

lower reaches of Darjeeling districts) and Andaman and Nicobar Islands (South Andaman, Middle Andaman, North Andaman, Katchal Islands and Great Nicobar Islands). Generally, mappable sizes of NR holdings were less in these states. All these states together accounted for only 1,959 ha of NR area.

Practical uses of NR distribution maps

Satellite-derived spatial distribution maps of NR area were analyzed for various studies to develop scientific outcomes which are beneficial to NR plantation sector. Natural rubber plantation map developed for South India was utilized for the development of Rubber Soil Information System (RubSIS) which is a WebGIS based online platform for soil fertilizer recommendation of NR plantations (Rubber Board, 2017). It was developed by integrating NR area maps, soil fertility maps, soil depth and discriminatory soil fertilizer recommendations in an open-source platform. Natural rubber farmers can freely access to soil fertility status of NR plantations using RubSIS (http://rubsis.rubberboard.org.in). Geospatial analysis of NR area, soil organic carbon and soil depth were integrated and analyzed to calculate the net savings by way of need-based fertilizer application in mature NR plantations which reduces the cost for NR cultivation (Pradeep *et al.,* 2019). On the basis of above parameters about 1,61,911 ha of mature NR area was suggested for skipping chemical fertilizers in traditional NR growing regions.

Natural rubber plantations were characterized according to elevation and slope which is useful for soil resource management of NR growing areas (Pradeep *et al.,* 2015). Agriculture drought in NR plantations was monitored by analyzing Vegetation Temperature Condition Index (VTCI) which was a proxy to detect drought stress (Pradeep *et al.,* 2016; Shebin *et al.,* 2014). Susceptible drought prone areas of NR plantations can be demarcated by continuous monitoring of VTCI. Further NR distribution maps were utilized for finding spatio-temporal changes of NR cultivation in NR growing states of Tamil Nadu, Karnataka, Tripura, and Assam (Meti *et al*., 2014; RRII unpublished data). GIS database of the rubber area can be utilized for developing a comprehensive geo-spatial information portal by integrating other spatial variables (soil fertility, climate, physiography, productivity *etc.*) pertaining to NR cultivation. Thus the utilities of GIS based NR plantation distribution maps are enormous and it is a geospatial assisted system for planning and management of NR plantation sector.

Future prospects of mapping NR plantations in the country

Further monitoring of NR plantations in the country is essential to obtain the latest acreage and monitor spatio-temporal

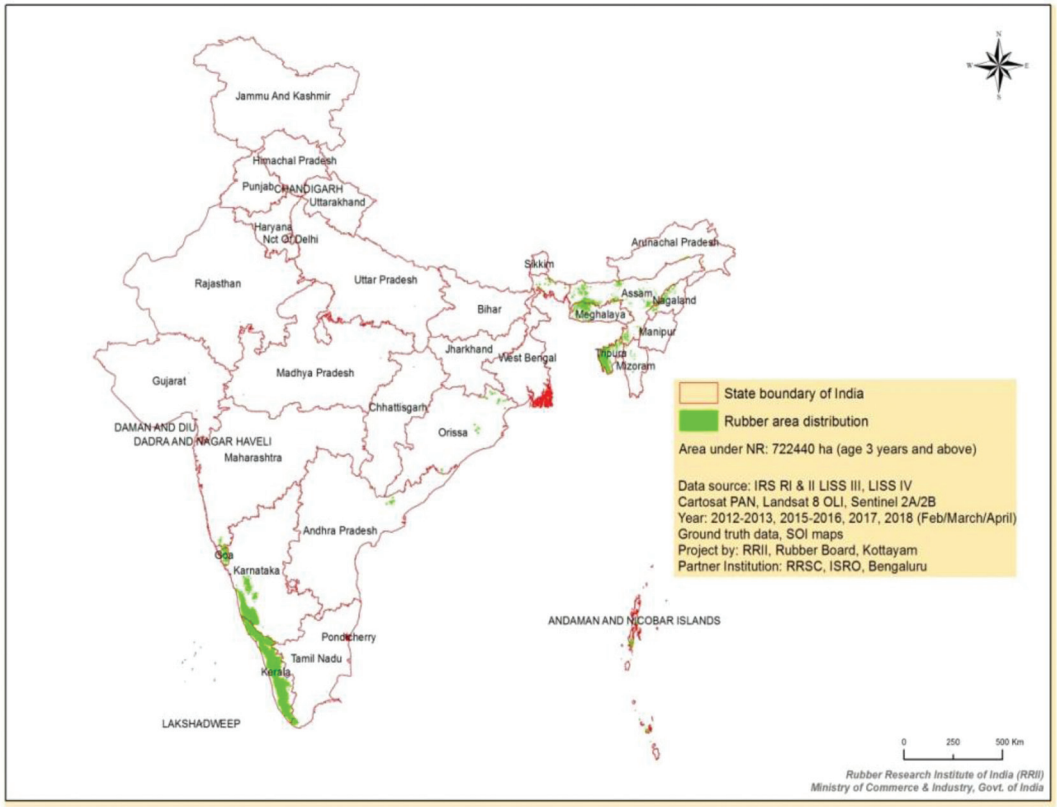

Fig. 4. Geo-spatial distribution of rubber plantations in India.

changes in NR cultivation. Earth observation satellite data which is freely accessible is of great use to monitor NR plantations at the national level. Landsat 8 OLI from United States Geological Survey (USGS) and Sentinel 2A/ 2B provided by European Space Agency (ESA) are well suited to monitor NR plantations. Apart from the optical data, microwave remote sensing data is an alternative which can be chosen if optical data is not available due to cloud/atmospheric noises. According to the scale and objectives of mapping, new methods of satellite data classification or analysis techniques can be adopted to reduce the time taken for mapping NR plantations in the country. Temporal updating of NR plantation maps and acreage will give a clear indication of the changes in NR cultivation in the future. Thus, operational monitoring of NR plantations in the country would help to take appropriate decisions to extend NR cultivation in a sustainable way by using geo-spatial assisted tools. Advanced remote sensing techniques such as drones (Unmanned Arial Vehicles - UAV) are now increasingly used to manage agriculture sector (Chong *et al.*, 2017; Sinha *et al.*, 2016; Sylvester, 2018). This would be useful for mapping of young NR plantations (age less than three years), stand age, tree count, wood

volume, leaf area index (LAI), biomass, pest/ disease surveillance *etc*.

CONCLUSION

Present study estimated an area of about 7.22 lakh ha of NR plantations of age three years and above from the NR growing states in India. Full mapping of NR plantations in the country was carried out for the first time and the study showed the potential of both Indian and foreign satellite data for mapping NR plantations. Nearly 77 per cent of total NR area was from the traditional region of Kerala and Kanyakumari district of Tamil Nadu. North-eastern states, the Konkan area of Karnataka, Maharashtra and Goa and the eastern states together contributed rest of the area. Natural rubber plantation maps need to be timely updated to get the latest acreage and for monitoring spatio-temporal shifts in NR cultivation in the country. The availability of open-access satellite data would be useful to produce the latest NR distribution maps at the national level. Scientific outcomes generated based on NR distribution maps are relevant for developing a comprehensive geo-spatial information platform that would act as an interactive GIS database of NR cultivation in the country. Combined uses of multi-sensor satellite data and advanced remote sensing technologies such as UAVs may become tangible tools for managing agriculture lands, including NR plantations in the future.

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