Chapter 12
Geospatial Applications in Inventory of Horticulture Plantations

H. M. Ravishankar, Shivam Trivedi, S. Rama Subramoniam, J. Mohammed Ahamed, T. R. Nagashree, V. B. Manjula, R. Hebbar, C. S. Jha, and V. K. Dadhwal

Abstract Horticulture is one of India's most important agricultural enterprises, driving the economy's growth. It is a key component for economic development in several states of the country and contributes around 30% to GDP of agriculture, with only about 8.5% of total agricultural area coverage. The lack of an authentic and holistic database on area and production was the major bottleneck limiting perspective planning of horticultural development in India. In this context, to realize the potential use of geospatial technology, several studies were initiated to establish the feasibility of high-resolution satellite data for discrimination of dominant fruit orchards and plantation crops using semi-automated object-oriented image analysis.

H. M. Ravishankar · S. Trivedi (✉) · S. R. Subramoniam · J. M. Ahamed · T. R. Nagashree · V. B. Manjula · R. Hebbar
Regional Remote Sensing Centre-South, NRSC, ISRO, Bengaluru, Karnataka, India
e-mail: shivamtrivedi@nrsc.gov.in

H. M. Ravishankar
e-mail: ravishankar_hm@nrsc.gov.in

S. R. Subramoniam
e-mail: ramasubramoniam_s@nrsc.gov.in

J. M. Ahamed
e-mail: mohammedahamed_j@nrsc.gov.in

T. R. Nagashree
e-mail: nagashree_tr@nrsc.gov.in

V. B. Manjula
e-mail: manjula_vb@nrsc.gov.in

R. Hebbar
e-mail: hebbar_kr@nrsc.gov.in

C. S. Jha
Regional Centres, National Remote Sensing Centre, ISRO, Hyderabad, Telangana, India
e-mail: jha_cs@nrsc.gov.in

V. K. Dadhwal
National Institute of Advanced Studies, Bengaluru, Karnataka, India
e-mail: vkdadhwal@nias.res.in

C. S. Jha et al. (eds.), *Geospatial Technologies for Resources Planning and Management*, Water Science and Technology Library 115,
https://doi.org/10.1007/978-3-030-98981-1_12

The major fruit crops covered were mango, citrus, banana, and grapes, while the nut crops included coconut, arecanut, oil palm, and cashew nut. Multi-resolution and temporal high-resolution data, in conjunction with the GPS-guided ground truth collection, was utilized in these studies. Hybrid semi-automatic classification techniques employing both digital classification and visual image interpretation were employed for spatial delineation of extent of horticultural plantation crops. It was concluded that single date high-resolution data corresponding to month of February–March would be most optimal for delineation of major plantations crops such as mango, citrus, coconut, arecanut, and cashew nut while for banana and grapes multi-temporal data was more suitable for successful inventory. The classification accuracies mostly ranged between 80 and 90%, depending on various factors, viz., age of plantation, extent of heterogeneity, plant spacings canopy cover, agronomic practices, etc. The methodologies for the identification and mapping of various horticultural plantations are established for selected study regions, mainly in peninsular India. Based on the encouraging results and successful completion of pilot projects, these studies were upscaled to regional/national level projects under the auspices of the Ministry of Agriculture. Fruit crops namely Mango, Banana, Citrus & Grapes, and a major nut crop, Coconut were successfully inventoried for major regions of the country. Relevant site-suitability analysis for mango, the king of fruits, has also been carried out by integrating terrain and pedo-climatic parameters under a GIS environment. This chapter summarizes the above efforts and achievements for mapping and monitoring important horticultural crops of India.

Keywords Horticulture · Plantations · Fruits · Semi-automatic classification · Object-oriented image analysis · Hybrid approach · Visual interpretation · Ground truth · Accuracy assessment · Geospatial technology · Deep learning · Site-suitability

12.1 Introduction

12.1.1 Importance of Horticulture

India is bestowed with varied agro-climatic conditions, which are highly favorable for growing many horticultural crops. Globally, India stands second in terms of production of fruits and vegetables (NHRDF 2019). The horticulture crops are an integral part of food and nutritional security and an essential ingredient of economic security. Thus, the horticulture sector in the country has been undergoing a sea change, both in terms of area, production, and productivity. India has emerged as a leading horticultural crop-producing country globally, with a total annual output of 240 million tons of horticulture crops. Areal extent under horticulture in India during 2015–16 was statistics indicate the vital role of horticulture in the Indian economy, in terms of generation of employment, higher farm profitability due to better price realizations, providing

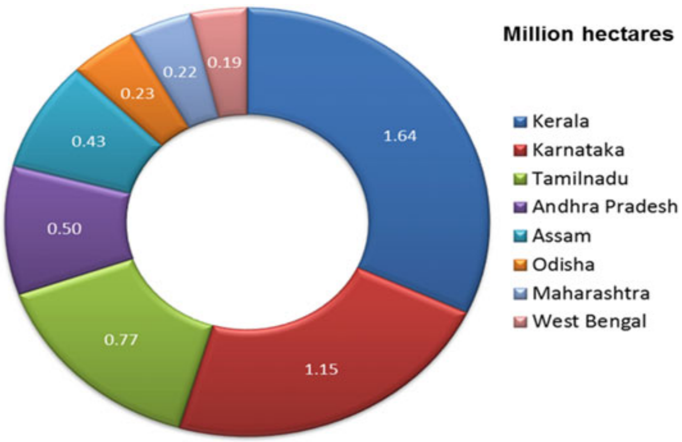


Fig. 12.1 State-wise area distribution under major plantation crops in India

ingredients for several by-products in food-processing industries under value addition chain, and stabilizing the country's balance of trade through export earnings. More than 95% of plantations are cultivated in the eight major states of India, while southern four states, Kerala, Karnataka Tamil Nadu, and Andhra Pradesh (including Telangana), alone contribute more than 75% of the total area and production of plantation crops (Fig. 12.1). Reliable statistical database, both area and production, at different spatial and administrative hierarchies is the fundamental requirement to promote growth of the horticultural sector in the country. In this context, geospatial technology provides an ideal framework for the generation of geodatabase on the spatial extent of horticultural crops at a disaggregated level.

The existing micro-level information base for horticulture plantations is mostly non-spatial or generalized spatial format. Requirement of the database on spatial distribution of major plantations, at large scales, was a felt need during early part of twenty-first century to meet the operational requirements of different segments of horticulture at micro to macro levels. Remote Sensing Satellite data with medium and coarse spatial resolutions have been used operationally for agricultural crop classification and monitoring (Dadhwal et al. 2003; Murthy et al. 2007). However, organized feasibility studies for establishing the use of geospatial technology for inventory/mapping of dominant fruit and plantation crops are, thus far, inadequate. Even though very few discrete studies had been attempted in this direction, a really organized and institutional effort covering multiple fruit and horticulture plantation crops did begin only during 2012. As a first step, pilot studies covering important plantation crops to develop operational methodologies for inventory were attempted. These studies primarily employed a hybrid approach, a combination of semi-automatic object-based classification and limited manual refinement.

As almost 85% of horticulture plantations, in terms of areal extent, are geographically distributed in peninsular India, majority of the pilot studies were carried out in this region (Fig. 12.1). This chapter summarizes the details of pilot studies for methodology development initially, followed by the operational execution of these techniques or methodologies in inventory of dominant fruit and plantation crops, besides site-suitability analysis, as confined to Karnataka, Tamil Nadu, and Kerala states.

12.1.2 Role of Geospatial Technology

With recent advances in space technology and the availability of high to very high spatial resolution satellite datasets and advanced classification techniques, geospatial technology is expected to play a pivotal role in geospatial database creation on horticulture crops, apart from facilitating the generation of databases on other related components. It has to be specifically mentioned here that such efforts have already covered inventory of commercial plantations, namely tea, rubber, and coffee but were lacking to fruit and plantations crops (RRSSC-B 2001; RRSC-East 2014; RRSC-South 2012, 2019).

Conventional per-pixel classifiers have limited utility for identifying and delineating horticulture crops as large spatial heterogeneity limits the realization of reasonable accuracy (Hebbar and Rao 2002; Srivastava and Gebelein 2007). Object-based image classification technique is a powerful, promising method for classification of high-resolution remote sensing data through the conversion of image pixels into objects using both texture and contextual information. Object-based image classification techniques provide more relevant information at multiple spatial scales than pixel-based classifiers (Gamanya et al. 2007). The main advantage of using object-oriented image analysis is the flexibility in defining various parameters for image objects at intended scales, viz. spectral reflectance, object-textures, feature-shapes, context relationships, apart from integrating both spatial and non-spatial additional collateral information (Bock et al. 2005).

In the Indian context, first-ever operational inventory was carried out for rubber plantations using high-resolution Cartosat-1 and LISS-IV data covering Tripura state, primarily employing onscreen visual interpretation technique. In the same study, site-suitability analysis for identifying suitable wastelands for expansion of rubber cultivation was also carried out (RRSC-South 2012). The utility of a hybrid approach for delineation of banana orchards using a combination of object-based approach and post visual classification editing was demonstrated using high-resolution data (Kasper et al. 2009).

In the background of advancements in space technology, advanced techniques for classification of available indigenous high-resolution satellite data, need for kick-starting the generation of hierarchical (macro to micro levels) geospatial databases on inventory and site-suitability, a series of feasibility studies covering multiple fruits and plantation crops, with the avowed intention of possible operationalization to regional/national levels, were initiated.

12.2 Pilot Studies for Methodology Development

Under ISRO's Earth Observation Applications Mission (EOAM), Regional Remote Sensing Centre-South (Bengaluru), of National Remote Sensing Centre, ISRO made concerted efforts during 2012–15, to study the feasibility of using high-resolution satellite datasets in association with temporal, multispectral datasets for inventory of dominant fruit orchards and plantation crops covering representative regions. Identification and methodology development for inventory of four fruit crops (mango, citrus, banana & grapes) and four plantation crops (coconut, arecanut, oil palm and cashewnut) was carried out under this EOAM project. Specific study areas covered represented diversified agro-climatic regimes of India.

Study area details along with selected horticulture crops are mentioned in Table 12.1: (i) Mango: Malihabad taluka, Uttar Pradesh (ii) Citrus: Sivagiri taluk, Tamil Nadu (iii) Banana: Guntur, Andhra Pradesh (iv) Grapes: Chikaballapura, Karnataka (v) Coconut: Tiptur taluk, Karnataka (vi) Arecanut: Chennagiri, Karnataka (vii) Oil Palm: Rajanagaram mandal, Andhra Pradesh and (viii) Cashewnut: Mandasa mandal, Andhra Pradesh. High-resolution Resourcesat-1 and 2, LISS-IV MX (5.0 m), and Cartosat-1 (2.5 m) data corresponding to 2013–14 were used under the study, along with Resourcesat-1 and 2 LISS-III (24 m) data.

Generalized methodology is depicted in Fig. 12.2. The major steps covered included (i) Satellite data processing (ii) GPS-guided Field data collection (iii) Classification (iv) Post classification refinement. Under all the studies, the collection of relevant ground truth information on crop of interest and competing crops and other classes was conducted in the selected sites/districts for its utilization in digital classification and accuracy assessment (Fig. 12.3). The sample sites were identified based on pre-field interpretation of the satellite data using tone and texture. Information such as sample sites and their locations, crop type, and age of crop, along with geotagged field photos, were organized in a GIS environment for generating a digital library of ground truth. Basically, a semi-automatic classification approach has been employed for the inventory of the majority of the chosen crops, and this approach

Table 12.1 Details of pilot study sites for fruit orchards and plantation crops

S. No.	Plantation crop studied	Taluk/mandal	District	State	Average rainfall (in mm)
1	Mango	Malihabad	Lucknow	UP	963
2	Banana	Guntur region	Krishna	AP	33
3	Citrus	Sivagiri	Tirunelveli	TN	815
4	Grapes	Chikkaballapura	Chikkaballapura	Karnataka	756
5	Coconut	Tiptur	Tumkur	Karnataka	660
6	Cashewnut	Mandasa	Srikakulam	Karnataka	1067
7	Arecanut	Chennagiri	Davanagere	Karnataka	809
8	Oil palm	Rajanagaram	East Godavari	AP	1100

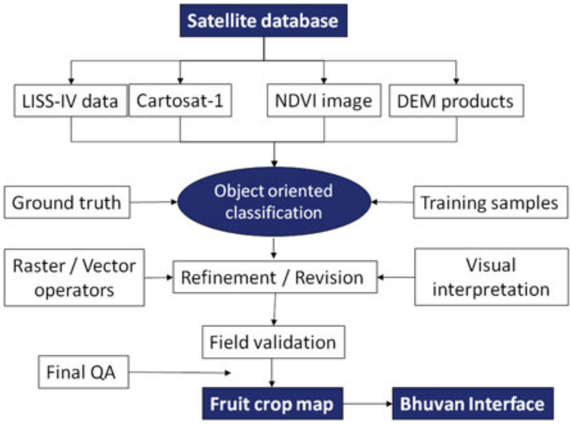


Fig. 12.2 Overall methodology flowchart for inventory of fruit orchards and plantation crops using semi-automatic classification approach

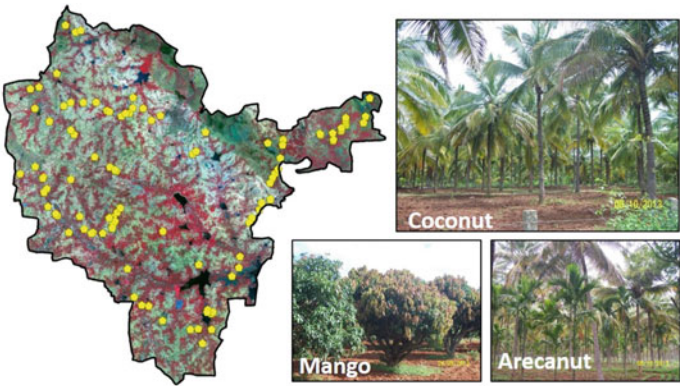


Fig. 12.3 GPS-guided ground truth collection in Tipaturu taluk, Tumakuru district, Karnataka for coconut plantations and other classes

envisaged an appropriate mix of object-oriented classification followed by limited onscreen visual editing.

The details of the pilot studies carried out for individual fruit orchards and plantation crops are discussed below.

12.2.1 Mango Plantations

Mango (*Mangifera indica*) is the king of the fruits with immense economic importance and is generally an alternate bearer (alternatingly yielding high and low during consecutive years), it is found imperative to generate a scientific spatial database of mango orchards. Toward this end, part of Malihabad taluk (Lucknow district, UP) has been taken up for the study. The mango orchards in Malihabad are densely spaced and contiguously placed, apart from remaining evergreen (despite a dip in NDVI during dry February) althrough the year. In comparison, the surrounding agricultural crops are mostly harvested, post-monsoon, and the fields remain fallow by late Rabi/Summer. Owing to above phenomenon, the temporal NDVI response of mango was distinct from the agricultural crops.

Temporal LISS-IV data (5 dates during 2012–13), covering the study region was used to study NDVI response for discrimination of mango plantations, in order to select optimal window of remote sensing data (Fig. 12.4) February month data was found to be optimal for identification of mango plantations, as most of agricultural crops, barring wheat and paddy, would be harvested by then. Homogeneous, contiguous plantations could be delineated through object-based classification of high-resolution data. Mapping accuracy of 89.2% was achieved which could be further improved to 93.5% through limited onscreen editing by visual interpretation technique. However, a trial exercise was carried out for mango plantations in a contrastingly diverse agro-climatic setup in Southern India viz. Srinivaspura taluka (Kolar district, Karnataka) using temporal LISS-IV data did not achieve satisfactory results. This has necessitated the exploration of further finetuning of semi-automatic

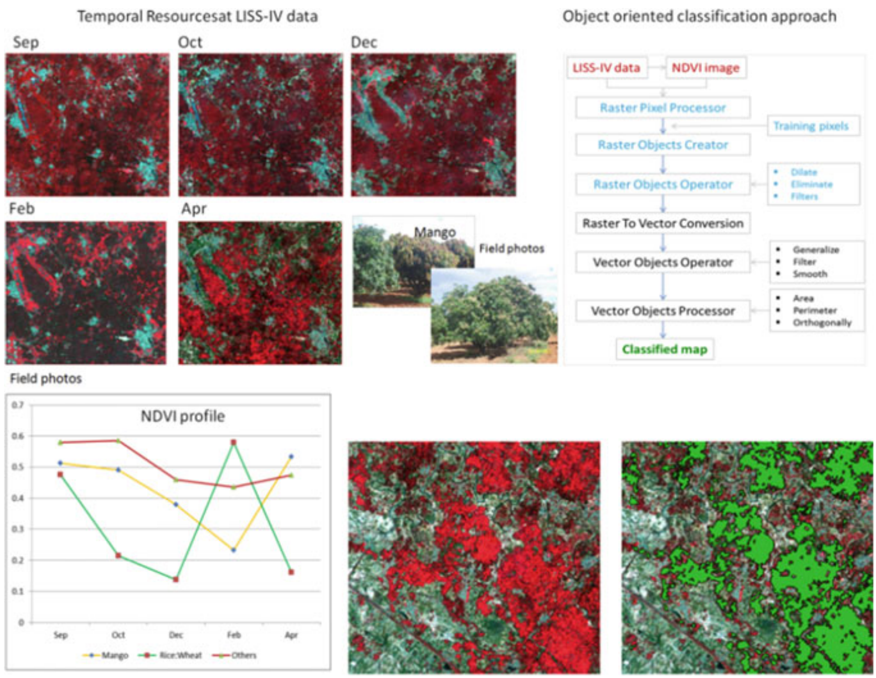


Fig. 12.4 Phenology study and inventory of mango plantations in Malihabad, UP

classification techniques for inventory of these plantations cultivated under diverse agro-horticulture systems, especially with wide inter-tree spacing and for very young orchards.

12.2.2 Banana Orchards

Banana (*Musa* spp.) is widely grown in India with great socio-economic significance; India is the largest producer of bananas in the world. It is well suited for cultivation from humid subtropical to semi-arid sub-tropics up to 2000 m above MSL. The banks of Krishna River in Guntur region have significant presence of banana orchards due to water availability from the river. Heterogeneous cropping pattern in this area also consists of chillies, cotton, citrus, paddy, and tobacco. With minimum soil exposure, banana orchards manifest in bright red tones, owing to dense and lush green canopy. However, a limited conflict with respect to spectral signatures of cotton and chilli crops in satellite data of October–November period. This specific spectral mixing necessitated minimum of two dates' data for classification of banana orchards. The intensive/contiguous cultivation of banana orchards, mostly in near proximity to the river, has favorably limited the temporal datasets to only two dates. Accordingly, multispectral LISS-IV data corresponding to April and June 2013 were chosen for the study, in spite of staggered planting of banana orchards.

Object-based classification has been employed here and the results as compared with field information are satisfactory as the spectral discernability favored improved classification of banana orchards (Fig. 12.5). Mapping accuracy of 91.4% was achieved which could be further improved to 94.6% through limited onscreen editing by visual interpretation technique. However, in places where the banana orchard

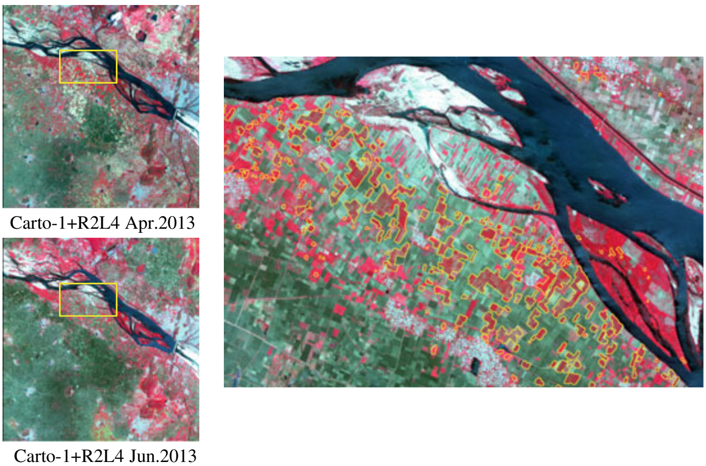


Fig. 12.5 Banana orchards in Guntur, Krishna district, AP

distribution is scattered and cultivation is not so intensive, two dates' data might not suffice. In such scenarios, temporal NDVI profiling might need to be carried out followed by a decision-rule-based hierarchical classification for better classification of banana orchards.

12.2.3 Citrus Orchards

Among the citrus types, Acid-lime (*Citrus aurangifolia)* is the most common type in Karnataka and Tamil Nadu. In Tamil Nadu state, Acid-lime gardens are dominant in Sivagiri taluk, Tirunelveli district, primarily cultivated for exports. The soils are mostly clay loam to sandy clay loam, and these areas fall under rain-fed regions. Temporal LISS-IV data analysis indicated the sufficiency of satellite data of two specific periods (corresponding to October and March–April months) were ideal for identification and delineation of acid-lime (citrus) orchards from other crop and vegetation classes for achieving reasonable classification accuracy (Fig. 12.6).

Based on the NDVI profile, citrus orchards were distinctly identified as compared to surrounding crops. However, it is to be specified that the object-based classification has shown promising results only in dominant citrus areas coupled with well-established and managed citrus orchards. Mapping accuracy of 78.9% was achieved which could be further improved to 90.2% through limited onscreen editing by visual interpretation technique. On the contrary, in regions with scattered as well as young

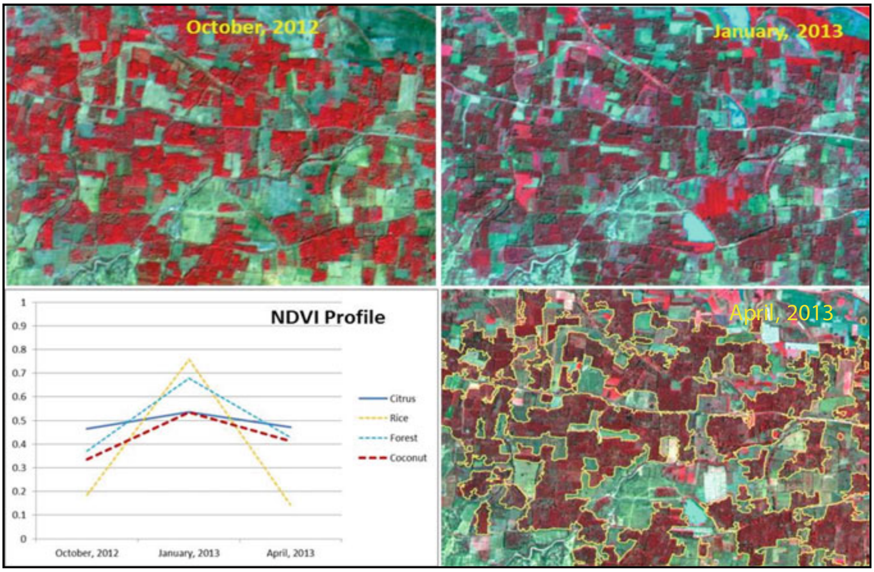


Fig. 12.6 Citrus orchards in Sivagiri taluka, Tirunelveli district, TN

citrus orchards, and also in situations where citrus is inter-planted with coconut, classification tends to be less accurate. Thus, it was concluded that this methodology needed to be deployed for citrus orchard dominant regions only, in similar agro-climatic dispositions.

12.2.4 Grapes Orchards

Grape (*Vitis vinifera*) is a very popular fruit crop cultivated in southern India, especially Karnataka and Maharashtra. It is a deciduous woody vine crop and its natural habitat is temperate and subtropical climate. In Karnataka, the cultivation of grapes is well managed but often restricted to small and medium land holdings, primarily in the districts of Vijayapura and Chikkaballapura. Chikkaballapura taluka is one of the major grape cultivation areas. Grape cultivation involves the unique agronomic practice of biannual pruning during October and April months and lush green leaves emerge after the pruning. Considering this, two date's multispectral datasets (LISS-IV) viz., Nov. and Feb. corresponding to pruning stage and post-pruning lush green stage (fruiting stage), respectively, were used for delineation of grape vineyards.

Object-based classification for delineation of grape orchards was carried out employing a total enumeration approach. In addition to the multispectral merged data corresponding to pre and post-pruning stages, LISS-IV NDVI images of the two dates were also used for classification. LISS-IV and Cartosat-1 merged data covering Chikkaballapura taluka and part of the classified image viz. Figure 12.7 depicts the

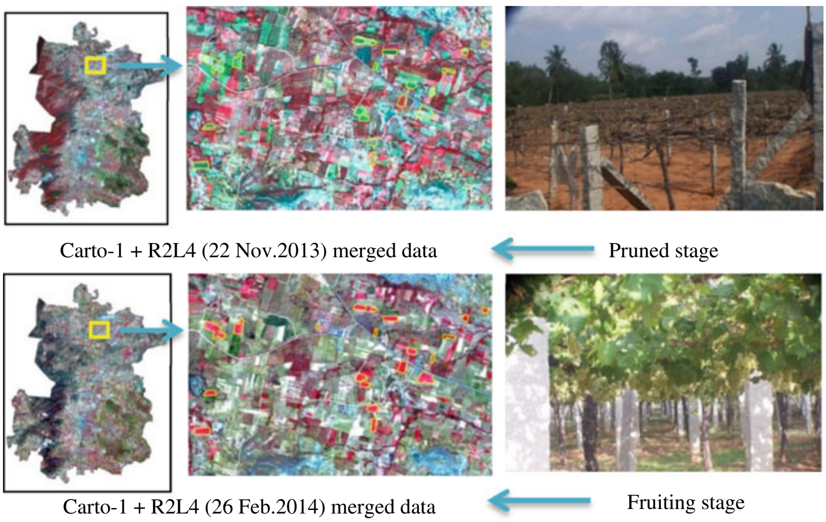


Fig. 12.7 Grape orchards in Chikkaballapura taluk, Karnataka

distribution of grape orchards in the study area. The hectarage of 1321 ha estimated through this technique compared fairly well with reported hectarage of 1705 ha (Dept. of Horticulture), indicating a relative deviation of −29%. This discrepancy is primarily owing to the fact that many of the fields with vegetable crops have spectrally/texturally confused with the greenness pattern of grape orchards during the pre-post pruning periods and thus resulting in underestimation of grape orchards.

Secondly, many of the grape orchards in the study area happen to be the demonstration plots maintained by many agri-business companies and do not strictly adhere to the standard temporal windows for pruning. These problems to a large extent can be overcome using multispectral data corresponding to pre and post-pruning stages of April pruning, in addition to October pruning. A mapping accuracy estimated using limited ground truth observations indicated an accuracy of just around 75%. Most misclassified grape orchard locations happen to be categorized as vegetable fields. It was concluded that the accuracy can be improved through the approach of using a simple NDVI based hierarchical decision rule-based approach using the above four datasets would also help in achieving better statistical and spatial accuracies in addition to object-based classification.

12.2.5 Coconut Plantations

Tipaturu is the cradle of coconut cultivation in Karnataka state and is the major contributor for edible coconut oil production as well as *copra* accounting for almost 35% of the total geographical area of the taluka as per conventional estimates. Coconut plantations in the taluka dot the entire agriculture landscape. As Coconut tree is evergreen, minimal temporal NDVI variations were observed. Figure 12.8 depicts distribution of coconut plantations using LISS-IV and Cartosat-1 data employing object-based classification techniques. As seen, plantations are spatially denser in the southern half of the taluka and the extreme eastern portion. The area estimated through remote sensing-based approach (26,085 ha) compared credibly with that of Dept. of Horticulture, Govt. of Karnataka (28,012 ha). The % relative deviation has worked out to a mere −7.39%. This is basically because the coconut plantations in the taluka are predominantly pure and not mixed with other plantation crops except in selected pockets. Only in the central region of the taluka, arecanut is found to exist as an intercrop in coconut plantations.

Even these regions have been mapped as coconut plantations only. Coconut plantations in certain pockets with shallow gravelly soils and poor groundwater availability lacked sufficient greenness and thus have gone unclassified under this approach. The same may however be accounted for through limited visual interpretation techniques. In a nutshell, results clearly demonstrated the use of February–April months high-resolution data for inventory of coconut plantations. Datasets corresponding to this period coincide with non-agricultural season facilitating better discrimination

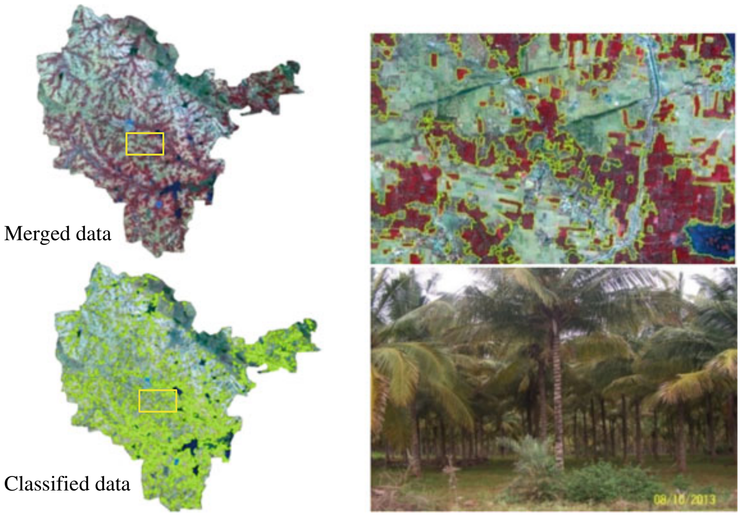


Fig. 12.8 Coconut plantations in Tipaturu taluka, Tumkur district, Karnataka

of coconut. However, due to intrinsic issues associated with poor spectral signatures from young plantations and poor stands of plantations, the same was not accurately classified. It is also to be noted that remote sensing-based approach does not account for the isolated individual rows of coconut trees raised along the field bunds/boundaries. Exclusion of these might slightly influence the extrapolation of area figures to production estimates.

12.2.6 Arecanut Plantations

Single date LISS-IV and Cartosat-1 merged data was used for delineation of arecanut plantations using object-based classification technique. The entire agricultural landscape of taluk has varying degrees of the presence of this plantation. The crop is generally well managed and grown in medium to large holdings.

In general, the crop is grown as monocrop, however, it is also cultivated along with several plantations such as coconut, banana, etc. Spatial expanse of arecanut crop in Chennagiri taluk is depicted in Fig. 12.9. The area estimated through remote sensing-based approach (16,389 ha), again, as in case of coconut in Tipaturu, compares credibly with that of Dept. of Horticulture, Govt. of Karnataka (18,032 ha). The % relative deviation has worked out to −10.02%. The following intricacies have been noticed during the object-based analysis for arecanut plantations:

- Replanting of arecanut is a temporally continuous phenomenon in the context of this crop and the taluk is no exception. Those of the very young fresh and replanted plantations have not been accounted for, during the analysis.

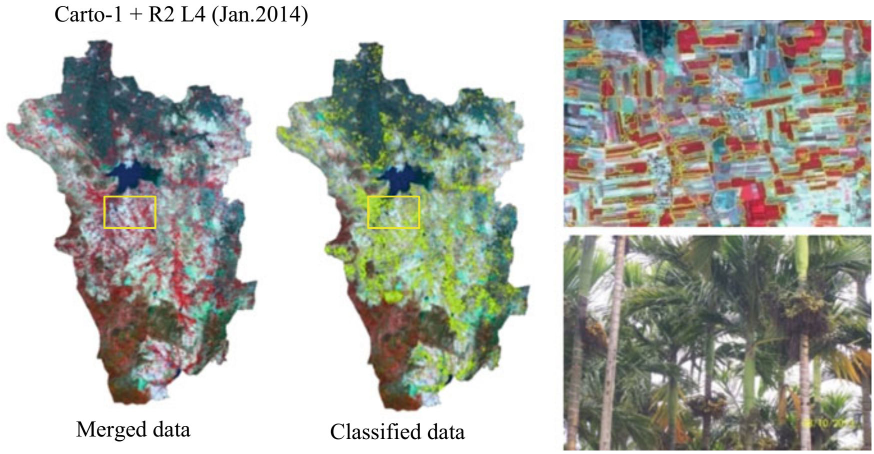


Fig. 12.9 Arecanut plantations in Chennagiri taluk, Davanagere district, Karnataka

- Arecanut being a water-intensive plantation, during the period coinciding with the date of satellite data acquisition, those of the land parcels where groundwater had depleted, the plantations exhibited desiccation and thus were spectrally not discernible.
- Some of the arecanut plantations raised in association with coconut and also having other annuals as intercrops exhibit different spectral signatures. Although a majority of these have been delineated under the approach, the area figures might slightly influence the extrapolation of area figures to production estimates.

12.2.7 Oil Palm Plantations

Our country has been plagued with shortage of edible oil production, ever since independence. Toward mitigation of this perennial problem, the Government of India initiated various measures to augment the oil-seed production adopting a two-pronged approach. On one hand, area under seasonal oil-seed crops was enhanced and on the other, perennial edible oil crops like oil palm were introduced in suitable areas, predominantly in the states of Andhra Pradesh and Karnataka. Oil Palm (*Elaeis guineensis*) is the highest oil-yielding plant among perennial oil-yielding crops, producing palm oil and palm kernel oil.

The West Godavari, East Godavari and Krishna districts of Andhra Pradesh extensively cultivate oil palm and, in this study, Rajanagram Mandal of East Godavari district has been considered for oil palm area estimation. Rajanagram Mandal is also characterized by the presence of two other major horticultural plantation types viz. Cashewnut and Coconut. A unique methodology has been adopted for classification/delineation of oil palm plantations using both object-based techniques as well as visual interpretation approaches. This was basically adopted to evaluate the spatial

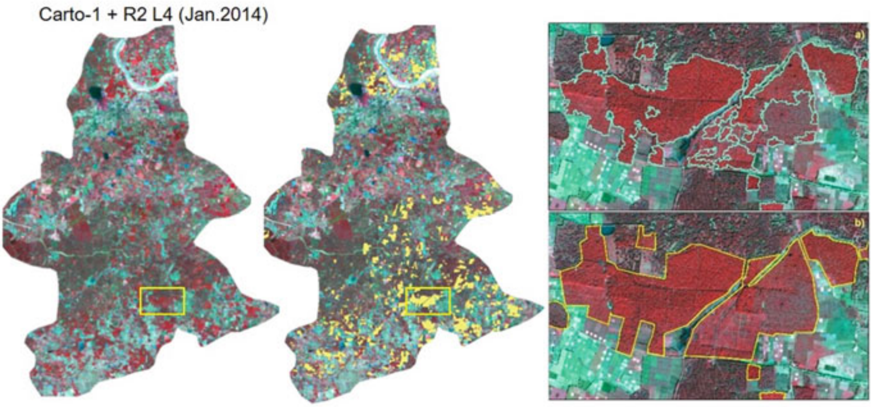


Fig. 12.10 Oil palm plantations in Rajanagaram, Andhra Pradesh **a** object-based classification and **b** visual interpretation approach

mapping accuracy of the semi-automatic approach in comparison to the standard interactive onscreen visual interpretation approach.

The object-based classification carried out using LISS-IV data corresponding to mid-June of 2014 merged with Cartosat-1 data of Nov. 2011 resulting in total oil palm area of 1939 ha (Fig. 12.10). The classification was facilitated with the unique crisscrossing diagonal planting pattern adopted for oil palm in this region as opposed to the normal horizontal-vertical pattern practiced for coconut. Cashew plantations, owing to their contrastingly different textural patterns did not spectrally/texturally confuse with oil palm classification. Onscreen interpretation approach for mapping oil palm plantations resulted in an estimation of the spatial extent of 1886 ha. In comparison of the maps generated using the two approaches, it is evident that semi-automatic classification has classified some of the coconut plantations also as oil palm and missed out on the younger as well as ill-managed oil palm plantations owing to their different spectral/textural characteristics. But the twin issues were obviated by adopting the onscreen approach. The very fact that both the approaches have resulted in near-similar area estimates is a testimony for semi-automatic classification being highly successful for accurately mapping oil palm plantations.

12.2.8 Cashewnut Plantations

Cashew plantations are predominantly found in parts of Srikakulam district, both as pure patches and also in mixed plantations (predominantly with coconut trees). Mandasa taluka, Srikakulam district in Andhra Pradesh was selected as the study area. Cashew plantations do are not planted in regular and defined patterns and manifest as irregular patches with rough texture in darker reddish tones on high-resolution

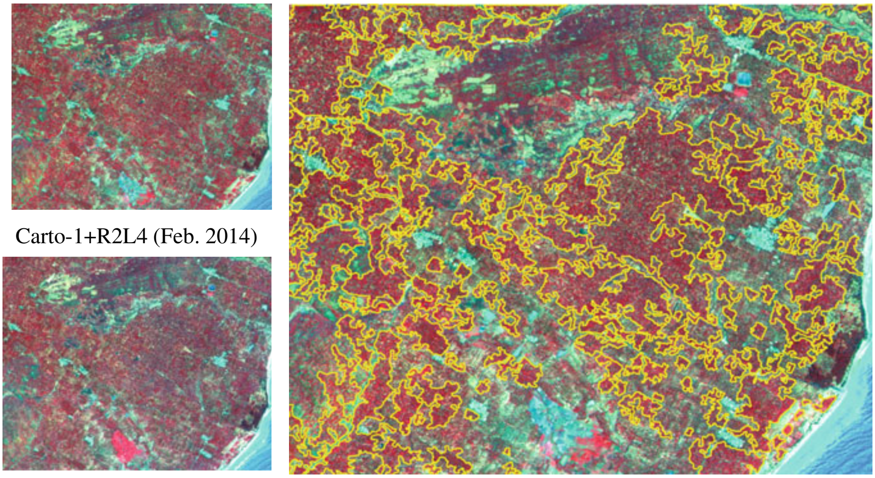


Fig. 12.11 Cashewnut plantations in Mandasa taluka, Srikakulam district, Andhra Pradesh

satellite data (Fig. 12.11). Additionally, the interspersion with coconut trees/small plantation patches makes the application of object-based classifiers further difficult. Thus, the semi-automatic classifier tried out in this region has shown mixed results, better being in patches with cashew nut trees domination and poorer in regions, where other trees co-existed with cashew nut plantations.

Results of the pilot studies covering few crops have been documented earlier (Hebbar et al. 2014).

12.3 Upscaling of Pilot Studies to Regional/National Level

The techniques and methodologies developed during successful conduct of the pilot studies covering inventory of eight different fruit and plantation crops, paved the way for upscaling of the studies to entire peninsular India. This was under a national initiative on "Coordinated program on Horticulture Assessment and Management using GeoiNformatics (CHAMAN)" launched by MNCFC, Department of Agriculture and Cooperation in collaboration with ISRO. The prime objective of CHAMAN was to realize the potential applications of emerging technologies such as remote sensing, GIS, and GPS for an inventory of horticulture crops for overall development of horticultural sector. During Phase-I of this program, RRSC-South, NRSC, and RRSC-Central took the lead role in implementing CHAMAN activities for the Peninsular Indian region with respect to three major fruit crops viz. Mango, Banana and Citrus (Phase-I). As many as 25 districts were covered for inventory, on an operational mode, by RRSC-South. During the Phase-II of the CHAMAN program, development of techniques for Coconut and Grapes apart from methodology for site-suitability analysis for mango was taken up in nine districts by RRSC-South. Deliverables under Phase-I were also hosted on Bhuvan Geo-platform.

12.3.1 Inventory of Mango Plantations and Banana and Citrus Orchards Under CHAMAN Phase-I

Study areas chosen under CHAMAN Phase-I program for inventory of Mango plantations and Banana and Citrus Orchards are mentioned in Table 12.2.

Satellite Data Used

Multi-resolution datasets were used in the project for mapping of fruit orchards in the selected districts in Karnataka and Tamil Nadu states (Tables 12.3 and 12.4).

Methodology

The general methodology followed for hybrid classification approach employed digital as well as visual interpretation techniques for delineation of spatial extent of horticultural fruit crops. The major steps covered included (i) Satellite data processing

Table 12.2 List of districts selected for inventory of mango plantations and banana and citrus orchards

S. No.	State	Crop	Selected districts
01	Karnataka	Mango	Kolar, Tumkur, Ramanagara, Bengaluru Rural, Chikkaballapur and Dharwad
02		Banana	Chamarajnagar, Mysore, Bellary, Ramanagara, and Tumakuru
03		Citrus	Vijayapura
04	Tamil Nadu	Mango	Krishnagiri, Vellore, Dharmapuri, Dindigul and Thiruvallur
05		Banana	Tirunelveli, Thoothukkudi, Tiruchirapalli, Erode, Coimbatore, Kanniyakumari, and Theni
06		Citrus	Tirunelveli

Table 12.3 Details of satellite data used under the study

Crop	Satellite data used	Purpose/role
Mango	Single date LISS-IV and Cartosat-1 data	Identification and area assessment
Citrus	Single/two dates LISS-IV and one date Carto-1	Identification and area assessment
Banana	3–4 dates LISS-III/Landsat-TM/Sentinel data Single/two date LISS-IV data	Phenology study Identification and area assessment

Table 12.4 Characteristics of remote sensing sensors used under the study

S. No.	Characteristics	Cartosat-1	RS-1		RS-2
			LISS-III	LISS-IV	LISS-IV
1	Spectral resolution (μm)	0.5–0.85	0.52–0.59 0.62–0.068 0.77–0.86 1.55–1.70	0.52–0.59 0.62–0.068 0.77–0.86	0.52–0.59 0.62–0.068 0.77–0.86
2	Spatial resolution (m)	2.5	23.5	5.8	5.8
3	Swath (km)	29/26	141	24	70
4	Radiometry	10	7	10 (7 bits transmitted)	
5	Repetivity (days)	126	24	24	70
6	Revisit (days)	5	24	5	5
7	Stereo	Fore/Aft	–	–	–

(ii) GPS-guided Field data collection (iii) Classification (iv) Post classification refinement (v) Bhuvan Interface.

Classification technique specifically involved the following steps: Hybrid approach using a mix of digital and onscreen visual interpretation techniques for delineation of fruit crops depending upon the suitability and intended accuracy. Object-oriented technique using e-Cognition software was used for classification of horticultural plantations. LISS-IV and Cartosat-1 were used as source data for multi-resolution segmentation. Optimizing segmentation parameters viz., scale, shape, and compactness were carried out iteratively based on visual inspection of the segmented images for their suitability for delineation of fruit crops. Initially, the segmentation was carried out with coarse-scale parameters for creation of cropped area masks using hierarchical classification. Second level segmentation was carried out within the crop mask with a finer scale parameter depending on the heterogeneity. The ground truth information was used for defining training sets for classification. Image features such as spectral mean, standard deviation, textural information like homogeneity, and NDVI were used in Support Vector Machine (SVM) based classification approach for crop inventory. Further refinement was done using geometry-based parameters (area, shape, linearity) followed by smoothening. In case of bananas, object-based classification approach with hierarchical rule sets was used for mapping followed by minimal interactive visual editing for revising the classified map.

Mango Plantations

Mango is the dominant fruit crop in the study districts, occupying large areal extents with marked differences in variety, age group, and management practices. Mango plantations exhibited in dull red color on the merged data with coarse texture due to wider spacing and partial soil exposure. Coconut is the other dominant plantation in some of the regions, manifested as dull red color but in clear-cut rows patterns due to canopy architecture and defined spacing. Typical spectral signature of major

Fig. 12.12 LISS-IV + Cartosat-1 merge data showing spectral signature of various plantations

plantations as manifested on high-resolution LISS-IV + Cartosat-1 merged data is depicted in Fig. 12.12.

Object-based classification was employed for delineating mango plantations using tone, texture, geometry, and vegetation index. Mapping accuracy of about 75–85% could be achieved using object-based classification approach alone. Incremental improvement was achieved through refinement using interactive visual interpretation. The final results demonstrated mapping accuracies of about 90% for most districts using a hybrid classification approach, indicating the potential use of high-resolution data for the inventory of these plantations.

Table 12.5 shows district-wise acreage under mango plantations for 11 major districts of Karnataka and Tamil Nadu states and comparison with the official estimates of State Horticulture Department. Spatial distribution of the crop in Kolar district is provided as Fig. 12.13 Higher deviation in few districts could be attributed to higher proportion of very young plantations which could not be captured using satellite data.

Intricacies observed with respect to inventory of mango plantations are summarized below:

- Spectral signature of young mango plantations (less than 3–5 years old) is not very distinct and discrimination of such plantations using high-resolution data is challenging. Further, at any given period, young plantations of other plantation types like coconut, areca, citrus, etc. are coexisting in the region resulting in spectral confusion to some extent.

Table 12.5 District-wise RS based and conventional acreage estimates under mango

S. No.	District	RS estimates (ha)	Reported area (ha)	Relative deviation (%)
Karnataka				
1	Kolar	41,489	46,772	−12.73
2	Tumkur	16,198	15,110	6.72
3	Ramanagara	26,017	22,131	14.94
4	Bangalore rural	5414	7030	−29.85
5	Chikkaballapura	11,374	14,147	−24.38
6	Dharwad	9520	10,767	−13.09
	Total	1,10,012	1,15,957	−5.40
Tamil Nadu				
7	Krishnagiri	31,118	36,009	−15.72
8	Vellore	14,072	13,979	0.66
9	Dharmapuri	8015	7948	0.84
10	Thiruvallur	10,578	10,603	−0.23
11	Dindigul	Could not be done due to heterogeneity with mixed plantations		
	Total	63,783	68,539	−7.36

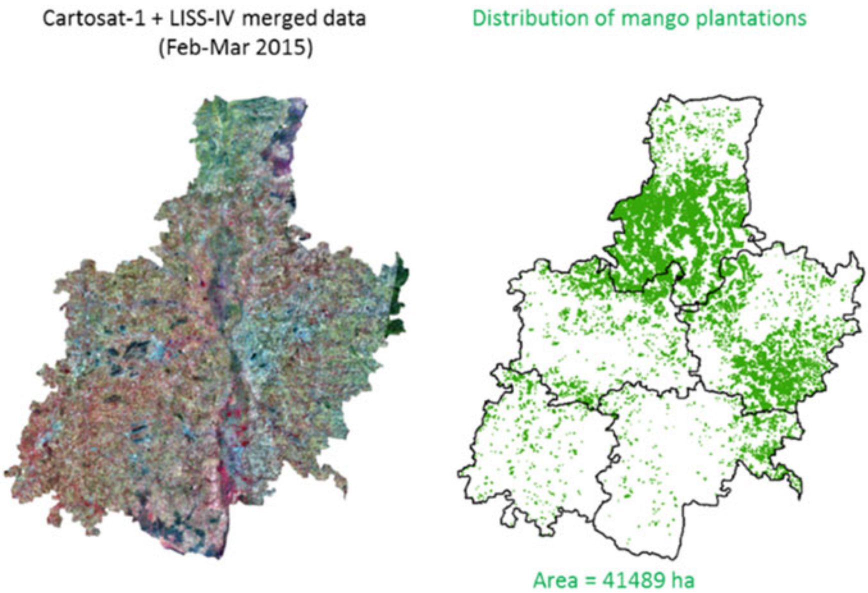


Fig. 12.13 Spatial distribution of mango plantations in Kolar district, Karnataka

- Spacing between mango plantations varies widely in the region with large variations in density, age, variety, etc. Thus, spectral confusion is noticed with the minor plantations such as sapota, tamarind, and guava, which occupy small fields and are scattered in these study districts.
- In some areas, the mango trees are along the bunds and marginal lands and cannot be identified easily on satellite data. Similarly, ill-managed plantations with higher mortality rates were also not identified properly.
- Tree density and age of mango plantations are critical inputs for production estimation and rejuvenation of old plantations. Attempts are being made to analyze the temporal and long-term satellite datasets to establish relative age groups and tree density broadly.

Banana Orchards

Globally, India stands first in production of bananas with diversified cultivation practices (with respect to planting periods, varieties, management practices, crop durations, and crop rotations) across different regions and more specifically between Tamil Nadu and Karnataka states. As opposed to highly staggered planting of bananas in Karnataka, planting within a narrow window of March–May in river flood-plains and irrigated regions of few Tamil Nadu districts, coupled with staggered planting in remaining districts is observed. Crop duration ranges between 10–12 months but will be limited and 6–7 months in case of crop raised for cutting plantain leaves only, for religious significance, and other commercial uses. Banana as monocrop is widely cultivated in selected districts of Tamil Nadu occupying large contiguous patches and growing in the same field for 4–5 years. In Karnataka, RS-based inventory complexities are associated with staggered and mixed planting, periodical cutting of leaves, understory planting, etc. (Table 12.6)

Phenological studies using temporal multispectral data were carried out and concluded that minimum of two date's data of Oct–Nov and Feb–Mar bio-windows, respectively, are best suited for improved discrimination of banana orchards from other coexisting long duration crops like sugarcane. LISS-IV data and other datasets (Tables 12.3 and 12.4) were used to classify banana orchards using a judicious mix of MXL, RGB clustering, and object-based classification techniques. The mapping accuracy ranged from 85.0 to 92.5% with an overall accuracy of 86.20%. District-wise acreages under banana orchards were estimated and compared with the official estimates (Table 12.5). The analysis establishes the potential use of high-resolution data for discrimination of banana orchards with reasonable accuracy for districts having homogenous contiguous areas. The lower RS acreages estimate in few districts are due to mixed and multi-tier cultivation practices, small field size, and staggered planting, especially in Karnataka and two districts of Tamil Nadu. The spatial distribution of banana orchards in Thoothukudi district, Tamil Nadu is shown in Fig. 12.14.

Intricacies observed with respect to mapping/inventory of banana orchards are summarized below:

Table 12.6 District-wise RS based and conventional acreage estimates under banana orchards

S. No.	District	RS estimates (ha)	Reported area (ha)	Relative deviation (%)
Tamil Nadu				
1	Tirunelveli	7015	7176	−2.30
2	Thoothukkudi	7893	8973	−13.68
3	Tiruchirappalli	7214	6913	4.17
4	Erode	7735	9618	−24.34
5	Coimbatore	5530	8115	−46.75
6	Theni	5814	6093	−4.80
7	Kanyakumari	2040	6383	−212.89
	Total	43,241	53,271	−23.20
Karnataka				
8	Bellary	3016	4993	−65.60
9	Ramanagara	3560	4004	−12.47
10	Tumkur	3624	4572	−26.15
11	Mysore	Mapping was not satisfactory due to complex agronomic practices (staggered and mixed planting, periodical cutting of leaves, understory planting, etc.)		
12	Chamarajnagar			
	Total	10,200	13,569	−33.03

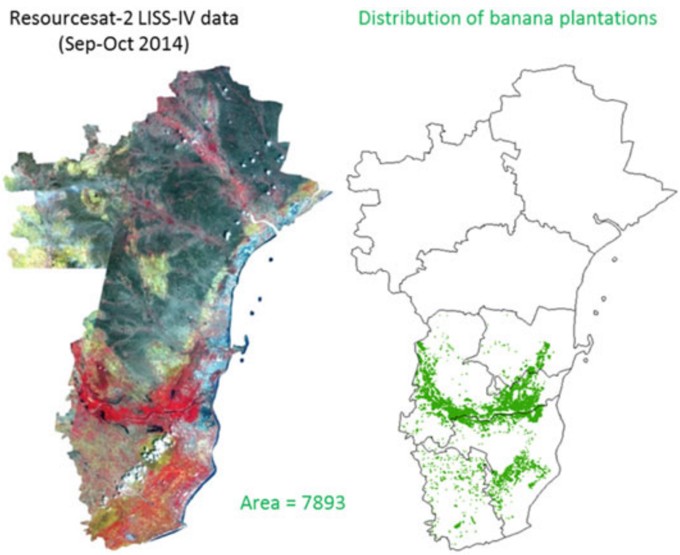


Fig. 12.14 Spatial distribution of banana orchards in Thoothukudi district, Tamil Nadu

- Although single date LISS-IV data is found to be fairly useful for delineating contiguous banana orchards in Tamil Nadu, two date data corresponding to Oct–Nov and Feb–Mar months are ideally suited for improved discrimination in the two states. Availability of optimal cloud-free datasets is a major constraint in some regions.
- Banana orchards in Karnataka are characterized by staggered planting period with peak period from June to December requiring temporal satellite data for identification.
- In general, mixed and two-tier cultivation of banana with coconut/areca plantations is very common, a sustainable farming practice in Karnataka. Mapping mixed plantations using high-resolution data is challenging and needs further detailed studies.

Citrus Orchards

Predominant Citrus category fruits cultivated in Karnataka and Tamil Nadu are lime and lemon. Citrus cultivation in these two states is characterized by small field sizes, sparse distribution with different age group categories, and distribution across the study areas. Besides citrus orchards, grapes, pomegranate, and sugarcane are also cultivated. Identification of citrus orchards is relatively easier in homogenous and large contiguous areas using single date LISS-IV and Cartosat-1 merged data. Object-based classification using spectral and texture information was used for delineation of citrus orchards using Cartosat-1 and LISS-IV merged data. Discrimination of citrus orchards from pomegranate and grape orchards was difficult to a limited extent and required minimal visual editing. The results were reasonably accurate for old and mature orchards with mapping accuracy ranging from 85.0 to 90.5%. The remote sensing-based citrus crop acreage estimates are compared with the official estimates and presented in Table 12.7. The analysis clearly showed that the RS estimates closely match official estimates for all districts. Spatial distribution of citrus orchards in Vijayapura District, Karnataka is shown in Fig. 12.15.

Bhuvan Interface

The output maps depicting the spatial distribution of the three fruit crops in different study districts and geotagged photos (collected during Ground Truth Visits) were hosted on BHUVAN geo-portal for visualization in an exclusive web page for the

Table 12.7 District-wise RS based and conventional acreage estimates under citrus orchards

S. No.	District	RS estimates (ha)	Reported area (ha)	Relative deviation (%)	Mapping accuracy (%)
1	Vijayapura, Karnataka	6936	6499.0	6.3	85.0
2	Tirunelveli, Tamil Nadu	2024	1747.0	13.7	90.5

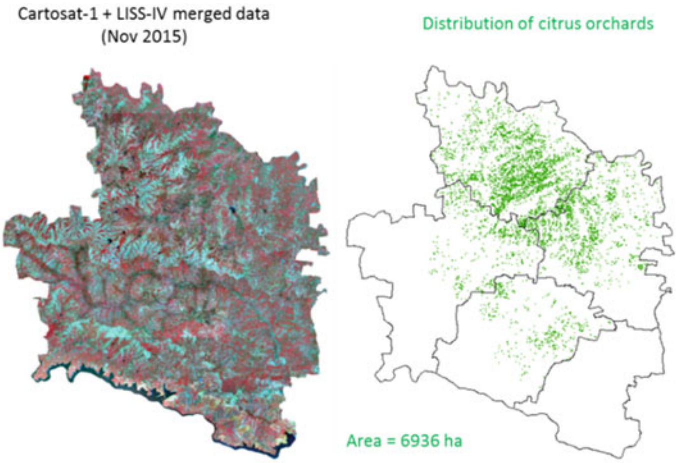


Fig. 12.15 Spatial distribution of citrus plantations in Vijayapura district, Karnataka

CHAMAN program. The same is depicted in Fig. 12.16. (http://bhuvan.nrsc.gov.in/governance/moa_chaman).

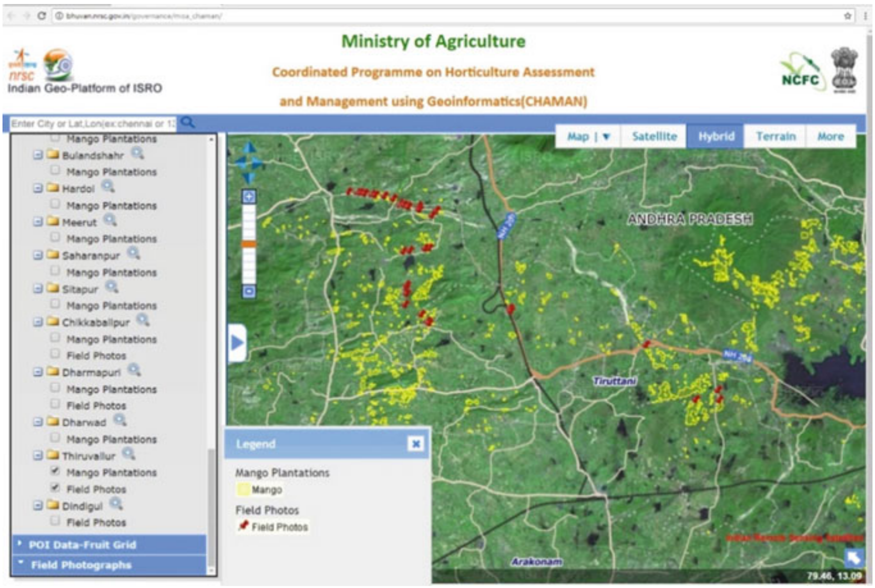


Fig. 12.16 Screenshot of project deliverables in Bhuvan interface

Table 12.8 List of districts covered under CHAMAN Phase-II program for coconut plantations and grapes orchards' mapping

S. No.	Crop	State	District
1	Coconut	Kerala	Kozhikode, Malappuram, Kannur, Kasaragodu
		Karnataka	Tumkur
		Tamil Nadu	Coimbatore
2	Grapes	Karnataka	Chikkaballapura (Chikkaballapura taluk)
		Tamil Nadu	Theni (Uttamapalayam taluk)

12.3.2 Technique Development for Coconut Plantations and Grapes Orchards' Mapping Under CHAMAN Phase-II

With the successful completion of inventory in operational mode for mango, banana, and citrus crops, technique development studies have been carried out during 2018–2020 Coconut Plantations and Grapes Orchards' mapping, at RRSC-South. A total of eight districts have been covered under this program (Table 12.8), predominantly using 2.5 m Cartosat-1 + LISS-IV satellite data.

12.3.3 Coconut Plantations

India is the third-largest coconut-producing nation globally, occupying 21.50 M ha and production of 21,228.2 M nuts with a productivity of 9897 nuts/ha (CDB, 2018–19). The coconut plantation is cultivated across 17 States and 3 UTs covering diverse agro-climatic conditions. The four southern states of Kerala, Tamil Nadu, Karnataka, and Andhra Pradesh are the major coconut-producing states which account for more than 90% of area and production in the country. Coconut plantations being evergreen in nature, variation in temporal NDVI are minimal as a pure crop. February–April months satellite data was found to be best suited for mapping coconut plantations. Coconut plantations in the selected districts occupy large areal extents with marked differences in variety, age group, mixed cropping patterns, and management practices. Coconut plantations are manifested in typical spectral signature with row patterns with coarse texture on the high-resolution satellite data in well managed orchards (Fig. 12.17). However, coconut is cultivated in multi-tier cropping systems with other crops like banana, arecanut, etc. Identification of only coconut trees under such complex cropping systems is quite challenging. Hence, the coconut plantation map and acreage estimates consist of pure coconut stand as well as the mixed plantations.

Object-oriented classification was found to be the appropriate technique for delineating coconut plantations using tone, texture, geometry, texture, and NDVI.

Fig. 12.17 Spectral signature of coconut and other plantations on high-resolution data

Cartosat-1 + LISS-IV merged data and classified maps for few selected districts are depicted in Fig. 12.18. Mapping accuracy was better than 85.0% for Tumakuru, Kasaragod, Kannur, and Coimbatore districts, while Kozhikode and Malappuram showed 81.4 and 78.3%, respectively. Incremental improvement inaccuracies are possible through limited interactive visual interpretation. The district-level acreage estimates coconut plantations along with the reported area is depicted in Table 12.9.

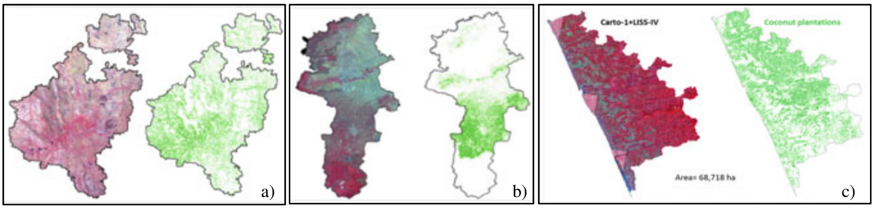


Fig. 12.18 Coconut plantation maps in **a** Tumakuru **b** Coimbatore and **c** Kasaragodu districts

Table 12.9 District-wise RS based and conventional acreage estimates under coconut plantations

State	Districts	RS estimates (ha)	Reported area (ha)	% RD	Mapping accuracy (%)
Karnataka	Tumakuru	207,000	179,000	13.53	>85%
Kerala	Kasaragodu	68,718	67,085	2.38	
	Kannur	76,002	85,972	−13.12	
	Malappuram	98,993	105,090	−6.16	78.3
	Kozhikode	122,878	112,305	8.60	81.4
Tamil Nadu	Coimbatore	81,917	87,000	−6.21	>85%

The table indicates that the relative deviation ranged from −13.12 to 13.53%. The lower accuracy in some of the districts is mainly due to mixed crop patterns and young plantations in the study area. The study indicated the potential of high-resolution data for the inventory of coconut plantations within reasonable accuracy. The use of very high-resolution Cartosat-2 series data and the development of deep learning techniques for mapping coconut plantations are being explored for improvement of classification accuracy and generation of operational procedures.

The intricacies observed in mapping of coconut plantations are as given below:

- Spectral signature of young coconut plantations (less than 3–5 years old) is not very distinct and discrimination of such plantations using high-resolution data is challenging.
- In some areas, the coconut trees are along the bunds and marginal lands and cannot be identified easily on satellite data.
- Spatial resolution used in current analysis may not be sufficient for improved discrimination, especially in heterogeneous and scattered regions and thus very high, sub-meter resolution data where the coconut trees are clearly discernible due to their distinct crown structure would be better suited.

12.3.4 Grapes Orchards

Inventory of grape orchards was carried out for two major taluks viz., Chikkaballapura Taluk Chikkaballapura district, Karnataka, and Uttamapalyam taluk, Theni district of Tamil Nadu using LISS-IV + Cartosat-1 merged data employing object-based classification. Grape orchards showed bright red color on the high-resolution data with smooth texture. It was observed that other plantations of the study area like mango, eucalyptus manifested as deep red color with coarse texture and were spectrally different from grape orchards as depicted in Fig. 12.19 However, spectral signature of short duration vegetable crops was mixing with grape orchards to limited extent.

The temporal Sentinel-2 MX data analysis revealed that two date's data of Nov-Dec and Feb-Mar bio window are best suited for improved discrimination of grape orchards from other coexisting short duration crops. Due to the non-availability of cloud-free high-resolution data, the alternatively available best datasets were used for the study. The mapping accuracy was about 85% for both the study areas. The lower accuracy is attributed to mixing of spectral signature of grape and other competing vegetables crops and accuracy could be improved using two date satellite data. Spatial distribution of grape orchards of Uttamplayam taluk, Theni district is depicted in Fig. 12.20. The crop acreage estimates of grape orchards corresponding to Chikkaballapur and Uttamapalyam taluks are shown in Table 12.10. The results showed that the acreage estimates for both study areas were lower compared to the reported area with a relative deviation of about 11.00%.

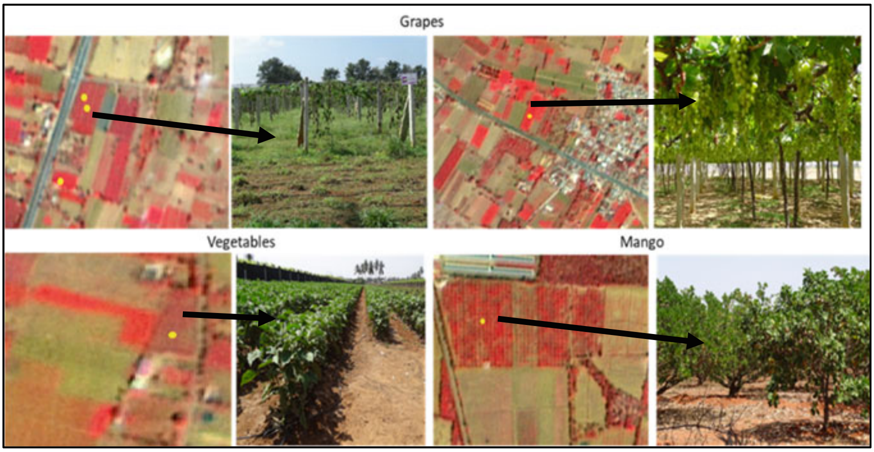


Fig. 12.19 Spectral signature of grape orchards and competing crops

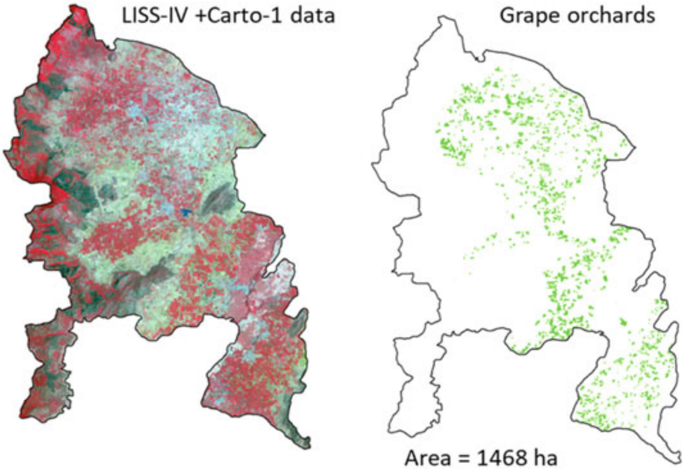


Fig. 12.20 Spatial distribution of grape orchards in Uttamapalyam taluk, Theni, Tamil Nadu

Table 12.10 District-wise RS based and conventional acreage estimates under grape orchards

S. No.	Taluk/district	RS estimates (ha)	Reported area (ha)	Relative deviation (%)
1	Chikkaballapur taluk, Chikkaballapur district, Karnataka	2250	2500	−11.11
2	Uthamapalyam, Theni district, Tamil Nadu	1250	1468	−11.48

12.3.5 Technique Development for Site-Suitability Analysis for Mango Plantations

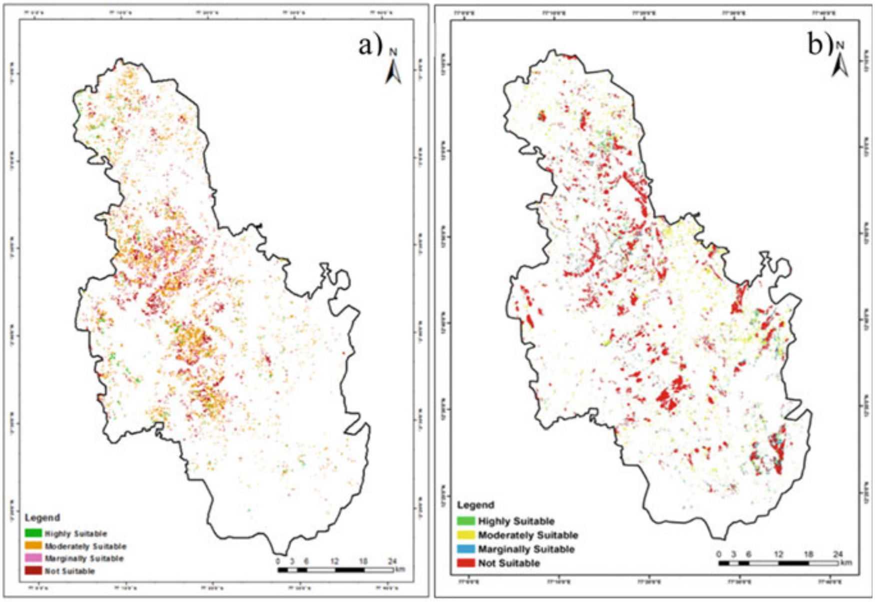
Mango, being a premium export potential fruit, the scope for expansion of mango cultivation is immense. This has necessitated the current study for site-suitability analysis for mango plantations using pedo-climatic parameters. Ramanagara district of Karnataka state was chosen as the study area. This district also has a significant presence of mango plantations (around 26,000 ha), which facilitates validation of analysis outcomes with an existing scenario. A major part of the district is occupied by red sandy texture soil. Ramanagara district falls under single agro-climatic zone, i.e., Eastern Dry Zone- Zone-5. The maximum and minimum temperature in the district ranges from 29 °C to 36 °C and 15 °C to 20 °C, respectively.

District receives average rainfall of 822 mm. Apart from mango, the important horticultural crops of the district include coconut, areca nut, banana, citrus, beetle vine, and vegetable crops like tomato, brinjal, etc. High-resolution Cartosat-1 and Resourcesat LISS-IV data were used for identification and area assessment of mango plantations as detailed under Sect. 12.3.1. Analysis was carried out using a set of criteria pertaining to pedo-climatic and terrain variables and the list is enclosed in Table 12.11. Carto-DEM was utilized for generation of slope map and soil map at 1:50 K was used for extracting soil parameters like soil texture, pH, organic carbon.

Applying the soil suitability criteria developed by NBSS&LUP, the land site-suitability has been evaluated for soil and climatic parameters. Accordingly, three different categories of suitability under the existing overall land use, exclusively for the existing mango plantation areas as well as specifically under wastelands, have been derived. Results of the spatial analysis carried out study the distribution of existing mango plantations under different suitability regimes are indicated under Fig. 12.21a. The results indicated that about 60.0% of the existing plantations are cultivated in marginally suitable lands while only 13% in highly and moderately

Table 12.11 Pedo-climatic variables used for suitability analysis

S. No	Data used	Parameters	Source
1	Soil Map	• Texture, depth, salinity • pH, OC, salinity	1:50 and 1:250 K
2	Weather	• Temperature • Rainfall	MODIS/IMD
3	Soil MOISTURE	• Soil moisture availability • Length of growing days	MOSDAC/NRSC
4	Groundwater	• Water depth (point data)	Central ground water board
5	LULC map	• Waste lands	1:50 K map, NRSC
6	Crop map	• Mango plantation map	Chaman phase-1
7	Satellite data	• NDVI	LISS-IV and sentinel
8	DEM	• Slope map	Carto-DEM



Suitability Regimes	Area of Existing Crop (ha)	Per cent
Highly Suitable	1366	5.3
Moderately suitable	2011	7.7
Marginally Suitable	15604	60.0
Least suitable	7030	27.0
Total	26011	

S. N	Class	Area in ha	Per cent
1	Highly Suitable	338	1.04
2	Moderately Suitable	8353	25.8
3	Marginally Suitable	4225	13.1
4	Not Suitable	19359	59.9
		32275	

Fig. 12.21 Site-suitability analysis for mango plantations in Ramanagara **a** proportion of existing mango plantations under different suitability regimes and **b** potential area under wastelands suitable for mango plantations

suitable lands. About 27.0% of the mango plantations have existed in least suitable lands. Similarly, the analysis of wastelands (Open Scrub, Dense Scrub, and grazing lands) for mango plantation suitability has indicated that significant portion of the wastelands are only marginally suitable for mango cultivation, with only about 13% of wastelands being moderate to highly suitable (Fig. 12.21b). The approach adopted under this site-suitability analysis facilitates the identification of suitability regimes under already cultivated fruit crops, apart from identifying additional areas for expansion of crop cultivation. This information is very useful for stratifying crop productivity and production zones.

12.4 Conclusions

This chapter has covered studies under different programs of ISRO, as carried out at RRSC-South, of NRSC/ISRO. Initially, concerted efforts were made during 2012–15, to study the feasibility of using high-resolution satellite datasets in association with temporal, multispectral data in connection with identification and methodology development for inventory of four fruit crops (mango, citrus, banana and grapes) and four plantation crops (coconut, arecanut, oil palm and cashew nut). The techniques and methodologies developed during the pilot studies' successful conduct paved the way for upscaling of the studies to entire peninsular India. This was under a national initiative on "Coordinated program on Horticulture Assessment and MAnagement using GeoiNformatics" (CHAMAN). During Phase-I of this program, three major fruit crops viz. Mango, Banana and Citrus in as many as 25 districts were covered for inventory, on an operational mode. Deliverables under Phase-I were also hosted on ISRO's Bhuvan Geo-platform. During the Phase-II of the CHAMAN program, development of techniques for Coconut and Grapes apart from methodology for site-suitability analysis for mango was taken up in nine districts by RRSC-South.

During the first study on methodology development for 08 fruits and plantation crops, the following have emerged: Multi-resolution, multispectral and at times temporal high-resolution satellite datasets are found to be effective in inventory of the horticulture crops. Phenological studies using temporal LISS-IV data were useful in selecting bio-windows for optimum date/dates' data selection, especially with respect to mango, banana, grapes, and citrus orchards. A hybrid approach involving a judicious mix of semi-automatic object-based classifier and need-based manual editing has been found to be the most effective in achieving better accuracies. Plantations crops viz., coconut, arecanut, and palm oil showed promising results with single date LISS-IV and Carto-1 merged data using object-based classification technique. However, Cashewnut could not be successfully classified using the semi-automatic technique. Out of these, oil palm inventory in Rajanagaram was the most successful showing 92.1% mapping accuracy which further improved to 96.2% through onscreen visual interpretation. Arecanut and Coconut showed lower accuracy levels of 75.2% and 76.5%, which could be further improved to 87.6% and 88.9%, respectively through limited editing of the classified vector layers. Object-based classification technique was unsuitable for cashew nut plantations, and visual interpretation technique was the only feasible alternative for accurate delineation of cashew nut plantations.

However, with the advent of Deep Learning-based classifiers, fresh attempts can be made using very high-resolution satellite datasets, for cashew nut plantations. The fruit crops viz., mango, banana, citrus, and grapes (fruit crops) have exhibited satisfactory results with object-based classifiers. Among the four, mango, in Malihabad has resulted in 89.2% mapping accuracy, improving further to 93.5% (on limited visual-interpretation-based editing). Banana orchards alongside Krishna river in Guntur region have shown corresponding mapping accuracies of 91.4 and 94.6%. In both the above cases, temporal multispectral data has been utilized. Similarly, in case of citrus plantations in Sivagiri taluka two dates' multispectral LISS-IV data has been employed to achieve mapping accuracies of 78.9 and 90.2%. In case of the fourth fruit crop, grapes the agronomic practice of pruning has been utilized for optimum selection of data corresponding to pre and post pruning stages. This has resulted in 75.8% and 89.0% mapping accuracies, respectively. In all the studies, additional fine-tunings based on visual interpretation have significantly improved mapping accuracy. Thus, this hybrid approach has been adopted during the upscaling of inventory studies to regional/national levels, taking care of the following intricacies observed during the pilot phase. This methodology is most-suited primarily for homogeneous mapping parcels of plantations but is of relatively limited utility in case of heterogeneous parcels, apart from fragmented holdings and multi-cropped regions. Also, mapping of young plantations, plantations under agro-horticultural systems, and mixed cropping systems have also been found to be of lesser amenability. These studies were limited to smaller regions, thus necessitating further finetuning of hybrid approach while scaling up for automation of the classification procedure to regional/state levels for operational applications of high-resolution data.

Under Phase-I of the CHAMAN project during 2015–2018, inventory of three major fruit crops, namely mango, banana, and citrus, has been carried out in 25 major districts of Karnataka and Tamil Nadu. Multi-resolution datasets were used in the study for spatial inventory of fruit crops. Single date LISS-IV and Cartosat-1 data of February–March bio window were used for inventory of mango and two dates' data for citrus plantations. Multi-date LISS-III/TM/Sentinel data was used initially for phenological characterization and for selection of optimum dates of high-resolution data. Best suitable single/two dates' LISS-IV data was used for mapping of banana orchards. As in the pilot phase, in-season ground truth information was carried out in the selected districts for its use in digital classification and accuracy assessment. Hybrid classification techniques with a combination of object-based and visual interpretation techniques were used for delineation of fruit crops. About 75–85% accuracy could be achieved using segmentation-based classification and further improvement in accuracy was achieved using onscreen visual interpretation for updating omitted and committed classes. After quality checking and accuracy assessment, district-wise crop acreages were estimated.

The results indicated that single date LISS-IV and Cartosat-1 data were sufficient to delineate mango plantations with reasonable accuracy. Matured and older plantations could be classified with better accuracy, while the spectral signature of very young plantations (2–5 years) is not quite distinct and could not be mapped. The banana orchards could be mapped with reasonably good accuracy using LISS-IV data in the selected districts of Tamil Nadu since the crop is cultivated as monocrop occupying large contiguous areas. However, banana cultivation in Karnataka is diverse with staggered planting, small field sizes and under mixed agro-horticultural practices (majorly under coconut, arecanut, etc.) and hence, accurate classification of banana orchards is still quite challenging. Identification of citrus orchards is relatively easier in homogenous and large contiguous areas using LISS-IV + Cartosat-1 data. The plantation maps along with geotagged photos were hosted on BHUVAN geo-portal for visualization.

Under Phase-II of CHAMAN project, as many as eight districts from Kerala, Karnataka, and Tamil Nadu have been covered to develop optimum techniques/methodology for inventory of coconut plantations and grapes orchards. The study showed the potential applications of high-resolution satellite data (LISS-IV and Cartosat-1 data) for mapping important horticultural crops like grapes and coconut plantations using an object-based classification approach. In case of coconut, mapping accuracy was better than 85.0% for four districts but slightly lower for Kozhikode (78.3%) and Malappuram (81.4%) districts. The crop acreage estimates were closely matching with the reported area and relative deviations ranged from −13.12 to + 13.53%. Semi-automatic approach has exclusively proven its ability to map coconut plantations with reasonable accuracy. However, it is to be noted that young coconut plantations (less than 3–5 years old), as well as younger plantations of mango, citrus, arecanut and others coexisting in the region, might not be discernible using this technique alone. In case of grapes orchards, as in case of pilot study, minimum of two dates data have been found to be appropriate for improved discrimination from other competing fields and vegetable crops.

Site-suitability analysis was carried out in Ramanagara district, Karnataka, for evaluation of existing mango plantation areas as well as identification of additional areas under wastelands for extension of mango cultivation. About 60.0% of the existing plantations are cultivated in marginally suitable lands instead of a meager 13.0% in highly and moderately suitable lands. Spatial analysis of the cultivable wastelands has identified about 8600 ha of potential land (highly and moderately suitable) as suitable for expanding mango cultivation in the district. Integration of various pedo-climatic parameters showed promising results for suitability analysis for mango plantations, an important input for crop yield modeling and condition assessment.

12.5 Way Forward

Significant strides have been made in the field of utilizing geospatial technology as detailed in this chapter. However, there is still a major scope for covering the gaps in the already conducted studies as well as taking the applications of high to very high-resolution satellite datasets and also additionally utilizing latest ML/DL techniques for the following:

- Better spatial resolution data, preferably at sub-meter level (Cartosat-2 series and other similar sensors) need to be utilized for better discrimination of major fruit and plantation crops in order to achieve better accuracies, obviating the need for incremental editing through visual interpretation.
- Other economically important plantation and fruit crops such as Oil Palm, Pomegranate, Apple, Guava, Sapota, Ber, Litchi, etc. some of which are even grown in smaller and scattered plots also need to be inventoried using semi-automatic classification techniques.

- Advanced Machine Learning/Deep Learning techniques need to be utilized for development of appropriate classification models using training samples. These semantic segmentation models have the proven potential for applicability across different agro-climatic dispositions for various plantation crops. This approach would also, in the long run, facilitate generation of a GT library, in the form of training samples, and can be used periodically for inventory and change mapping.
- All the remaining major areas in the country in which the important fruit & plantation crops are cultivated, also need to be covered in stages. This would facilitate generation of individual crop maps at different administrative hierarchical levels (taluk to national level). This is the pressing need for policy decisions at different levels.
- Individual state and a national level fruit & plantation crop map need to be generated through integration of the outcomes of all above approaches. This shall form a basis for assessment of trees outside forests as part of agro-forestry system, in the country and also frame policies in connection with food and nutritional security in the country.
- Studies for use of geospatial techniques for crop yield estimation also need to be hastened up. Toward this end, the site-suitability evaluation studies in the all the major existing fruit & plantation regions need to be carried out to come out with production/productivity zones. Additionally, site-suitability analysis for necessary non-fruit and plantation regions also needs to be carried out for the possible expansion of cultivation. This is of utmost importance as horticulture produce have an in-built value addition component and thus area income accretive to the farming community.
- Sufficient studies need to be conducted to detect and managed of pests and diseases through the application of ML/DL techniques.
- A national level geospatial database on storage and marketing infrastructure is the need of the hour to supplement the market intelligence, manage demand–supply scenarios, and minimize the post-harvest losses (especially in case of perishable produce).

Acknowledgements The project team expresses its deep sense of gratitude to Director, the National Remote Sensing Centre (NRSC), for his constant encouragement during the studies. We are highly grateful to Shri Uday Raj (Former CGM, Regional Centres, NRSC/ISRO), Dr. K. Ganesha Raj (Former GM, RRSC-South, NRSC/ISRO) for their support, encouragement and valuable guidance during execution of these studies. We thank Shri B. Chandrasekaran and (Late) Shri S. Elango, Scientists, RRSC-South, NRSC, for their contribution in field data collection. We duly acknowledge the efforts of MNCFC Research Analysts Shri Nagoor Kani, Shri Surya Deb Chakraborty, Smt. Mamta Rana and Shri Ghanshyam Shrawankar for their unstinted involvement in different stages of both phases of CHAMAN program.

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