Chapter 8

Summary and Conclusions

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Early crop studies using space borne data employed visual mapping of crops in India which progressed into digital analysis in CAPE project after launch of IRS-1A. CAPE project which mainly depended on single date RS data classification approach at district level, further graduated into multi date RS data classification at National scale after launch of IRS-1C WiFS sensor system. Technological advancements in sensor system provided a new direction for crop assessment but at the same time posed various data analysis challenges. Present research study emphasizes the development of newer techniques of MRS data based crop discrimination and early estimation of crop area. Analysis has been done to address various issues associated with MRS data applications for assessment of crop, from district level to state level using optical data. The findings of the analysis, towards integration of multi-source normalized data, may help in strengthening the operational assessment of crops as well as planning of suitable space based crop observation strategy and data processing approaches.

This Study mainly focussed on four broad aspects of crop assessment as required by resource managers for proper planning and management:

(1) Advantage of coarse resolution multi date observations over high resolution single date approach in crop inventory by way of integrating the information from the two,

(2) Strategy and role of data normalization in multi date and multi-source observations,

(3) Use of historical knowledge in in-season assessment, and

(4) Development of an approach to address the issue of long term trends in crop area.

The research issues were arrived upon after discussions with higher management officials engaged in operational assessment and forecasting of crops at different levels. Analysis was carried out using IRS-LISS-III, IRS-AWiFS, and MODIS data to develop and demonstrate the new techniques involved in early crop assessment.

Important conclusions arrived from the study are as follows

(1) Multi date observations, starting from the sowing of crops, in relatively coarser resolution provide more precise and stable assessment as compared to single date high spatial

resolution analysis. Rabi crops and other vegetation with similar spectral behaviour at any particular date/time get resolved / discriminated by tracking the temporal behaviour of vegetation index.

(2) Advantage of multi-source and multi temporal information is associated with data normalization issues. Observations carried out at different times of the seasons, which represent the crop signatures, are affected by atmospheric noise associated with variability in aerosol optical thickness, water vapour, haze etc. Relative normalization technique, based on image characteristics, was found to be more appropriate in operational scenario as near real time input on atmospheric constituents are not available. Data normalization approach developed for crop assessment showed significant improvement in performance.

(3) In most of the methods of crop classification reported so far, only in-season data is analysed with ground truth information. It was observed during the study that availability of apriori knowledge of pixel level crop history over the region of interest drastically improved the performance. This apriori knowledge may be used for optimization of field surveys to reduce the burden on ground truth data collection. Judicious use of remote sensing based crop historical information as apriori knowledge of the area has been proposed. Analysis should be more focussed on the changing patterns.

(4) Apart from in-season crop assessment, inter annual trends of crop area and its vigour is also needed to assess the effects of agricultural practices and policies (also anthropogenic and effect of climate changes). A methodology was developed to assess the increasing/decreasing trends of wheat area in Gujarat. Normalised NDVI information, over years was found useful in delineating the regions of change.

The research study described in this thesis has been presented in eight chapters. While the research problem is posed in Chapter 1, the final conclusions derived from the research work are described in Chapter 8 i.e. the current chapter. A chapter-wise brief summary of the work is as follows:

8.1 Summary of the Thesis

The purpose behind taking up this study has been presented in the first chapter of this thesis. Food security is becoming one of the most alarming fields of concern for the global governments, decision makers, natural resource managers, and researchers due to the ever

increasing world population. In this chapter, multi-directional pressure on land resources has been discussed. The basics of RS techniques have been briefed and importance of deriving information on crop acreage using remotely sensed data has been discussed. The prime motivation behind carrying out this research was the unavailability of appropriate research studies on early estimation of crop sown area using synergistic use of multi-source data. Hence, after identifying the research gap area, research questions were designed. At the end of Chapter 1, the objectives defined for this study are presented.

The review of literature related to crop studies using RS data has been presented in Chapter 2. The chapter has been further divided into the following 3 sections:

1. Literature review of the crop studies using RS data, carried out in different parts of the world excluding India. It presents the development of the state of the art global scenario of research and technology in this field.
2. Literature review of the crop studies using RS data, carried out in India. It presents the developments in the field from beginning of RS in India to the current national scenario.
3. Literature review of the crop studies especially focused on classification of RS data. Different types of classifiers have also been introduced in brief.
4. Literature review of the studies especially focused on multi-source data applications for crop studies at different spatial scales.

The studies which have been included cover a variety of RS data acquired at different spatial resolutions and obtained from various satellite based sensors. Also, studies related to RS data classification, employing various types of classifiers, have also been included.

Chapter 3 presents the algorithms and the data mining techniques employed for modelling of the early crop area estimation in this study. The basis of selection of Albers Conical Equal Area (ACEA) projection, as the common spatial framework, has been explained. The Haze Optimization Transformation (HOT), which takes into account varying degree of thin cloud for radiometric normalization, has been discussed. To normalise multi-date RS data, Harmonic Analysis of Time Series (HANTS) analysis was carried out. Its implementation to normalise multi-date MODIS data has been demonstrated. The basic algorithms of Maximum

Likelihood (MxL), K-means, and ISODATA classifiers have been presented. The chapter ends with a description of the accuracy assessment of the classified images.

An experiment to develop a methodology for early estimation of Rabi sown area at district scale (typically study area less than 1 million hectare) using multi-source data has been described in Chapter 4. The study area, data used, adopted methodology, data analysis and the results of the study are presented. The challenges of using multi-source data have been identified and their solutions discussed. The geo-referencing of multi-resolution RS data has been discussed in detail. Multi-date data from Resourcesat-2 AWiFS and single date data from Resourcesat-2 LISS-III sensors were used for early estimation of crop acreage in Mehsana district of Gujarat state in India. The problems arising due to mixing of crop and plantations classes could be resolved using temporal NDVI patterns derived from multi-date integrated dataset.

Chapter 5 presents the technique developed for early estimation of crop sown area using multi-source data at state level (typically study area more than 10 million hectare). The Gujarat state (India) was selected as the study area (the geographic area is around 20 M ha). The methodology uses high temporal moderate spatial resolution data and low temporal high spatial resolution data. It also made use of previous years' data for extracting a-priori knowledge of crop sowing area. Early crop area estimate was made for Gujarat state for 2011-12 Rabi season. Multi-date MODIS data and two-date Resourcesat-2 AWiFS data upto mid-December were used. It is shown that incorporating two date AWiFS data and a-priori information with multi-date MODIS data increased the accuracy of crop sown area estimates.

It has been demonstrated in Chapter 6 that multi-date multi-year moderate resolution data can be used for assessing multi-year crop changes at the state level. The multi-date 8-day surface reflectance data of Terra MODIS over Gujarat state for 10 years has been used. Twenty three NDVI images were derived from the surface reflectance data for each Rabi season. From the analysis of multi-year NDVI time series data from 2002-03 to 2011-12, it has been concluded that there was considerable increase in area under Rabi season crops in Gujarat from 2002-03 to 2011-12 and that MODIS data can be used for monitoring gross annual changes of major Rabi crops at a regional scale.

Chapter 7 discusses the overall results of the research. The results obtained through three sub-studies are discussed. A major part of the discussion is devoted to the research questions and their proposed / obtained solutions. The last chapter of the thesis, Chapter 8 concludes the thesis with respect to the objectives defined at the end of Chapter 1. It summarises the thesis chapter-wise and points out the limitations of the technique developed in this study. It proposes future scopes of expansion and extension of the present study. The thesis ends with alphabetical listing of all the references cited in the thesis.

8.2 Limitations

The study presented in this thesis is carried out to demonstrate the feasibility of multi-source data for operationally estimating early Rabi crop area. All efforts are made to use the data and techniques which are easily available and provide accurate and effective results. There were some assumptions made during the analysis of the data and as a result the study has following limitations:

- Extensive use of multi-date 8-day MODIS reflectance data has been made because it is one of the best, publicly and freely available surface reflectance global data at moderate spatial and high temporal resolution. It is assumed that the data will remain easily available to the global community in the future too, as long as the satellites provide the data.

- In the light of the first objective of the study, a number of issues related to integration of multi-source data were identified. Some of the issues related to geometric & radiometric normalisation and dissimilar physical quantities have been resolved in the studies carried out. As the other issues (e.g. spatial and non-spatial data) were not relevant to these studies, they may be addressed in future.

- The MODIS 8-day surface reflectance product is available but with a time-lag. It will affect the timeliness in case of operational use of the methodology.

- In case of early Rabi crop estimation at district scale, it is assumed that a single date cloud free LISS-III data is available early in the season covering full district. This may

not hold true for operationalizing the methodology for all the districts in a state. A Similar situation may arise in case of two dates AWiFS data for covering full state.

- In Sub-study-A, only two classifiers were attempted: maximum likelihood and ISODATA clustering. The performance of other classifiers like Artificial Neural Networks (ANN), Support Vector Machines (SVM), Decision Tree classifiers may also be assessed.

8.3 Conclusion

The thesis presents a methodology which has potential for operationally estimating early Rabi crop sown acreage at different spatial scales. It involves management and analysis of multi-source data. It details the methodologies which have been developed for integrating MRS data for modelling early Rabi crop sown area at state and district levels. It shows how the information derived from previous years RS data can support the estimation of current year's early crop estimates. The approach integrates the spatial information available from external sources with previous and currents years limited RS data to extract the desired information. The integrated use of multi-source data provides timely information which otherwise can't be extracted from the analysis of any single dataset used in the study. The approach has been used to estimate early Rabi sown area of Mehsana district and Gujarat State for 2011-12 season.

The study uses RS data in different formats with appropriate management of spatial data from different sources. The RS data from three sensors i.e. Terra MODIS, Resourcesat-2 AWiFS, and Resourcesat-2 LISS-III has been used in these sub-studies. Multi-date MODIS data for 10 Rabi seasons i.e. 2002-03 to 2011-12 has been used for extracting the inter-seasonal information. Multi-date AWiFS data has been used to derive the crop information within a crop season. While low and coarse spatial resolution data from MODIS and AWiFS has been used for state level and district level studies; LISS-III data has been used for district scale study only. Crop classified images prepared from 5-years (2006-07 to 2010-11) of multi-date MODIS data over Gujarat have been used to derive a crop history image which is then used with in-season RS data for early estimation of crop sown area in the state. The land use land

cover data over Gujarat, available from external sources, has been used for masking out built-up and river flood-plain regions, which otherwise poses problem during classification. In the light of objectives identified at the end of chapter 2, the studies presented in this thesis may be concluded as follows:

Conclusion with respect to Objective 1: The objective was to identify the potential issues that affect the integration of multi-source data for crop studies and to demonstrate their solutions through a MRS data study for crop assessment. Through the sub-studies carried out using multi-sensor data analysis along with the information available from literature, many important issues related to integration of multi-source data have been identified and some of them are resolved. High degree of non-uniformity or dissimilarity among the multi-source data with respect to their characteristics creates hurdle in their synergistic utilization. For using this data available from multiple sources with such non-uniformities, it first needs to be normalised with respect to the dissimilar characteristics. Based on current studies and the literature survey, following are the major issues encountered during multi-source data integration:

(i) **The multi-source data may or may not have geo-referencing information or geo-referencing schemes of two or more datasets may be different**. The issue has been discussed with respect to the present studies; all the datasets are re-projected to a common geo-referencing system. The details of the common geo-referencing system adopted in the studies which have been presented in this thesis are given in Chapter 3, Section 3.5.

(ii) **The MRS data are acquired by different sensors with different spatial resolutions**. In two of the studies presented here i.e. Sub-study-A and Sub-study-B, multi-resolution images have been used. Instead of merging two resolution images before extracting the information, here information at two scales is extracted before integration. Also, a procedure adopted for accurate registration of two images with different spatial resolutions is presented in chapter3, Section 3.6.

(iii) **The data available from different sources are acquired under different viewing and atmospheric conditions.** Radiative Transfer (RT) based models or image based empirical models may be used for the normalisation of varied conditions due to viewing geometry and atmosphere. Image based Haze Optimisation

Transformation (HOT) and Harmonic ANalysis of Time Series (HANTS) algorithm are described in Chapter 3, Section 3.7.

(iv) **The multi-source data comprises of different physical quantities of the target i.e. spectral radiance, reflectance, emittance, backscattering coefficient etc.** Such conditions have been aroused in Sub-study-B. To resolve the issue, NDVI (Normalised Difference Vegetation Index) derived from the reflectance values from one sensor and radiance values from the other sensor are used instead of using absolute reflectance and radiance values. The NDVI, being a normalised ratio, may be considered comparable in such cases.

(v) **The raster data are stored in different formats** e.g. CEOS, TIFF, GeoTIFF, IMG, HDF-EOS, MrSID, NetCDF etc. An Image processing software package or a combination of a number of software modules that can accept all available formats, should be used for such data analysis. Erdas Imagine, ENVI, and ArcGIS are the major software used for raster and vector data analysis.

(vi) **The types of spatial data are different.** In case of raster and vector datasets, one data has to be converted into other's format before using them together. In such cases, the raster and vector data characteristics need to be taken into account before integration.

(vii) **The types of available data or information are different**. Spatial and non-spatial data integration is another major issue in multi-source data utilisation. No non-spatial data has been used in the present studies, hence this issues is not taken care.

Conclusion with respect to Objective 2: The second objective was to develop a methodology for early crop sown area estimation at district level (typically less than 1 million hectare area) and state level (typically more than 10 million hectare area) using multi-source data. The first part of the objective has been achieved by estimating early Rabi crop area for Mehsana district in Gujarat (India) for 2011-12 Rabi season using RS data from two sensors. Multi-date data from Resourcesat-2 AWiFS and single date data from Resourcesat-2 LISS-III sensors have been used for early estimation of crop acreage in Mehsana district of Gujarat state in India. The mixing of crop and plantations classes, which is a serious problem in single date LISS-III based classification could be resolved using temporal NDVI patterns derived

from multi-date integrated multi-source dataset. The classification obtained using integrated dataset yielded better discrimination between the classes. The crop acreage estimates determined from this classification (58.9 '000 ha) are closer to the expected crop acreage than those obtained from single date LISS-III based classification (72.8 '000 ha). This technique uses temporal information of crop growth embedded in high frequency data (AWiFS) and spatial information embedded in low frequency data (LISS-III).

The second part of the objective has been achieved by early estimating Rabi sown area in Gujarat for 2011-12 season (Sub-study-B). A technique for early estimating crop sown area over a large region has been developed using MRS data. Crop sown area of Gujarat state (India) for 2011-12 Rabi season is estimated by mid-December. The multi-source data used in this study included in-season MODIS 8-day composite, and two dates AWiFS data along with multi-year, multi-date MODIS derived crop history image. Initial crop growth trends in terms of NDVI values have been obtained from multi-date MODIS data from October to mid-December 2011. ISODATA clustering algorithm is used to cluster similar trends of temporal NDVI patterns. Spatial distribution of crop and non-crop fields/clusters is obtained from two dates' AWiFS data (November 17 and December 11). Integration of the temporal patterns derived from MODIS data, spatial clusters derived from AWiFS data, and a crop history image derived from multi-year MODIS data is carried out using hierarchical decision tree approach. Reference crop sown area has been obtained by using full crop season multi-date AWiFS data for 2011-12. It is found that the integration of in-season multi-source data provided crop sown area estimates which were closer to the reference estimates.

Conclusion with respect to Objective 3: The third objective was to develop a methodology for integrating information derived from previous multi-years RS data for current year's crop sown area estimation. This objective has been taken up in Sub-study-B while estimating early Rabi sown area over Gujarat. Multi-date MODIS data for 5 Rabi seasons (2006-07 to 2010-11) have been used for assessing multi-season presence of crop over each parcel of 250m. The season-wise classified images obtained from multi-date MODIS data for 2006-07 to 2010-11 have been used to obtain a crop history image to be further used as *a-priori* information for 2011-12 Rabi season. This crop history image has been used along with other multi-sensor data to estimate early Rabi sown area for Gujarat in 2011-12.

Conclusion with respect to Objective 4: The fourth objective was to use a coarse resolution RS data like that from MODIS for assessing multi-year crop area changes at state level. The objective has been achieved through Sub-study-C by assessing Rabi crop area, wheat crop area, and mustard crop area of Gujarat from 2002-03 to 2011-12 using multi-date MODIS data. The feasibility of utilizing MODIS time series data for Rabi crops area monitoring of Gujarat has also been evaluated. Multi-date MODIS surface reflectance data derived NDVI values of 2002-03 to 2011-12 (from October to March) have been used for classification of crops after smoothening of the data by Harmonic ANalysis of Time Series (HANTS) algorithm. For each Rabi season total 23 sets of Rabi seasonal NDVI time series were derived from eight-day composite images. The multi-date NDVI dataset has been classified using a hybrid approach primarily based on K-means clustering. The K-means based spectral clusters are labelled into different spectral classes using a spectral profile matching approach. This study shows that area under Rabi crop in Gujarat increased significantly from 2002-03 to 2011-12. Total area under wheat crop approximately doubled from 2002-03 to 2011-12, with an average rate of change of about 12.9% per year. Area under mustard crop initially increased from 2002-03 to 2006-07, with a total increase of 123% having been observed within these 5 years. However, later on from 2006-07 onwards, area under mustard crop decreased continuously, with a reduction of around 41% in 5 years. The rate of increase in Rabi crop area has been statistically tested and found to be significant at 90% confidence level. Average rate of change in the total area under Rabi crop over these 10 years was found to have increased by 8.6%.

8.4 Future Scope

It is expected that the world will need to feed a population of around 9.1 billion by 2050. To meet the food requirement of the population, production in the developing countries would need to almost double (GAT2050, 2009). Doubling the production will certainly require better management of our cropland area which stresses on the importance of timely information about the crop sown area. It indicates that the early estimation of crop area will become more important for agriculture managers and planners. Hence, there is an immediate need for developing and implementing a technique of early crop estimation using multi-source data.

The methodology presented in this thesis has the scope to be extended over other parts of the country at district and state levels. The MODIS data used in these studies is easily and freely available to the global scientific community. In case of continuity of this data in the same way (as long as the satellites provide the data), it can also be used to cover other districts and states of India. It can be expanded to the national level by incorporating low resolution and high frequency RS data. Although, the techniques used for deriving the information from MODIS data can be extended over any other data with similar characteristics available in the future.

To overcome the limitation due to the time-lag in obtaining the MODIS 8-day reflectance data, composite may be prepared from the daily MODIS reflectance product. Algorithms for cloud detection, haze suppression, and quality assessment need to be implemented.

India is planning to launch its first geostationary earth observation satellite, GISAT (Geo Imaging Satellite) in 2018 which will provide data in different spectral bands in VNIR (Visible Near Infra-Red), SWIR (Short Wave Infra-Red), and LWIR (Long Wave Infra-Red) sectors of the spectrum (DOS, 2013; Kiran Kumar, 2016; ILS, 2016; Madhumathi, 2016). A future road map for GISAT data products archival and dissemination has already been planned (Shah and Utkarsh, 2016). The methodology developed in the present study will also be useful for integrating GISAT data with LISS-III data.

Recent forest cover images may be obtained from Forest Survey of India and those images can be used for masking out forest area before subjecting RS data for classification. It will solve the problem of mixing of plantation crops with forest. The Microware remote sensing, passive or active, provides a very good data for estimating soil moisture in the agricultural fields. Some initial studies have demonstrated that the information about moisture content helps in the forecasting of crop sown area. Inclusion of the information on soil moisture in the current methodologies may further enhance the early assessment of Rabi crop area.

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