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Abstract

This study proposes an approach to develop a simple, time efficient and generic approach to assess and monitor tea plantations in Northeast India using time series remote sensing images. The tea industry in India is in a consolidation phase with the plantations suffering from yield decline and quality. Tea is affected by a plethora of factors including age, environment and management. Therefore, monitoring and analysing growth of tea plantations over space and time is a very important aspect. Remote sensing offers an efficient and reliable means of collecting the information required, in order to map tea type and acreage. Through the use of satellite imageries, information on the health of tea plantations can be extracted. The spectral reflectance of a tea field always varies with respect to the phenology, stage type and crop health and these could be well monitored and measured using multispectral sensors. Information from remotely sensed data can be integrated into GIS by combining with ancillary data which can provide insights to the cultural practices being implied into the cropping system. It will also help farmers identify areas within a field which are experiencing difficulties, so that they can apply, for instance, the correct type and amount of fertilizer, pesticide or herbicide. Using this approach, planters will not only improve the productivity of their land, but will also reduce farm input costs and minimise environmental impacts. Based on this, a stepwise approach has been designed to assess and monitor tea plantations in Northeast India.

Introduction

India continues to be the world's largest producer and consumer of tea. Domestic productions as well as exports have been on the rise. However, the country is facing stiff competition from countries like Sri Lanka, Kenya, China, Bangladesh and Indonesia, and issues of quality and realisations on Indian teas have been witnessing a downward trend. Statistics indicate that tea plants start yielding from the third year onwards, maintain a steady increasing trend upto a certain age and reach a peak followed by a decline, thus questioning the further commercial viability of the section (Dutta et al., 2010). The economic life of the bush has been estimated to be 40 years. After this, the amount of non-productive tissues of tea plants becomes so great that its maintenance adversely affects the production of new shoots (Hadfield, 1974). Even with best management practices, tea bushes still get infested with pests and diseases. This causes gradual decay and death, thus creating vacant patches in the field which increase with time, resulting in the loss of productive tea area.

Being a mono-cultured crop, tea has to stand in fields in situations with very less inter-culture operation and no crop rotation. Such conditions ultimately lead to degradation of soil environment and health of the bushes. The mono-culture of tea is said to cause a condition of improper soil functioning known as soil sickness (Barua, 1969). Because of these conditions, when a tea area reaches the economic life age, the section is uprooted and a new generation of young tea is planted. However, immediate replanting after uprooting has universally experienced serious establishment problems of young tea. Its stand and health remain far behind an average healthy young tea plant despite using best known growing techniques and inputs. To combat such situations after uprooting, Guatemala grass should be planted for 18-24 months which is said to rejuvenate the soil for replanting. Following rejuvenation, a desirable growth of young tea is usually noticed. However, a gestation period of 18-24 months has always been playing an important role in replanting as the break-even period of young tea including these two years becomes quite longer.

Soil fertility status has to be kept at an optimum level to achieve desirable yields. Soil health deterioration is a prime concern for tea gardens in India. In order to achieve high yields and quality, exact parameters on soil physics, soil biology and soil chemistry in relation to two years of rehabilitation/crop rotation period have to be stressed upon. It is also necessary to know the various inputs to soil which are being applied to increase the fertility and availability of organic carbon/potash/sulphur in soil so that effective soil management techniques can be put into action (Dutta et al., 2010). Pest and diseases are very important factors in the decline of yield and quality of tea (Dutta et al., 2008). According to these researchers, use of remote sensing could prove to be an important tool in monitoring the health of tea bush and also delineation of affected areas by pests and diseases. Water logging and floods have caused serious threats to low-lying gardens (Bhagat et al., 2009). As a result of water logging, yield and quality have considerably declined. The whole facet of water logging is on an upward trend and continues to include more and more gardens with the passage of time. It has been observed that the causes of waterlogging include eutrophication, man-made bunds and diversion of natural drainage channels by garden authorities. All these aspects form a very important area of research that will immensely help the tea industry in India.

Space technology which largely includes remote sensing and satellite communication systems, offers an efficient and reliable means of collecting the data/information required to map the tea types and acreage. Remote sensing through its satellite imageries provides the structure information on the health of the vegetation (Dutta, 2006). The spectral reflectance of a tea field always varies with respect to phenology, stage type and crop health and these could be well monitored and measured using the multispectral sensors. Information from remotely sensed data can be fed into GIS which when combined with ancillary data can provide deep insight into the cultural practice being implied in the cropping system. Stresses associated with moisture deficiencies, insects, fungal and weed infestations must be detected early enough to provide an opportunity to the planters for undertaking mitigation measures. Remote sensing would allow the planters to identify areas within a field which are experiencing difficulties, so that they can apply, for instance, the correct type and amount of fertilizer, pesticide or herbicide. Using this approach, planters can not only improve the productivity of their land, but also reduce farm input costs and minimizes environmental impacts. Remote sensing has a number of attributes that lend themselves to monitoring the health of tea plants (Dutta, 2006). Satellite imageries also give the required spatial overview of a large catchment or land which can aid in identifying the tea crops affected by too dry or wet conditions; by insect, weed or fungal infestations or weather related damage.

Examining the ratio of reflected infrared to red wavelengths is an excellent measure of vegetation health. This is the premise behind some vegetation indices such as the normalised differential vegetation index (NDVI). Healthy plants have a high NDVI value because of their high reflectance of infrared light, and relatively low reflectance of red light (Rajapakse et al., 2002). Phenology and vigour are the main factors affecting NDVI. It is possible to examine variations in tea crop growth within one field is possible. Areas of consistently healthy and vigorous crop would appear uniformly bright. Stressed vegetation would appear dark amongst the brighter, healthier crops. To achieve timely and accurate information on the status of crops, there is need to have an up-to-date crop monitoring system that provides accurate information. Remotely sensed data has the potential and capacity to achieve this. The use of remotely sensed data in crop acreage estimation has been demonstrated by various researchers across the world (Saha and Jonna, 1994). Remote sensing and crop growth simulation models are becoming increasingly recognised as potential tools for growth monitoring and yield estimation (Bauman, 1992). To harvest an everlasting benefit, the tea industry will have to take up uprooting and replanting in large areas at a time, while looking into the real scientific cause of the problem immediately after uprooting to reduce/remove the gestation period. To monitor the activities effectively and in real time, the use of space technology which may include remote sensing and a satellite communication and monitoring system is inevitable. Keeping in mind the various problems being faced by the tea industry (as outlined above), the proposed methodology is designed with the following long term and short term objectives.

Long term objective

The long term objective is to develop an interactive monitoring and decision support system framework using a systematic analysis of scaled (spatial/temporal) and geo-referenced data/information for tea plantations (with special emphasis on replanted crop) of Assam and North Bengal and conditioning variables (policy, infrastructure, markets, ethno-demographics) relevant for planning sustainable tea production.

Short term objective

Short term objectives are the following:

- To develop a geo-database of biophysical and socio-economic parameters of tea growing areas of Assam and North Bengal with special emphasis on soil parameters
- To study and monitor replantation activity of tea gardens using satellite imagery
- To monitor the extent of damage to tea plantations caused by pests, diseases and other biotic and abiotic stresses
- To develop drainage plans for tea plantations vulnerable to flooding using a GIS platform
- To develop a systematic decision support system framework for planning sustainable tea plantations.

Critical issues/research questions

The following are the critical research questions:

- How will radar image help in studying the soil status of tea plantations?
- How can high resolution satellite images help in delineating tea patches into different categories? (viz. pests and disease infestations, categorization of good and poor growth)
- Which classification will be more suitable for delineating tea patches?
- How can fuzzy classification help in solving multi-objective problems of tea?
- Is it possible to separate out mixed classes in tea using sub-pixel classifier?

- Which is the best fuzzy technique to identify a particular tea garden from a landuse/landcover map?
- What will be the role of multi-temporal data in carrying out this research?
- How will spatio-temporal analysis and decision support tools help in strategic planning and management of tea plantations?

Study area

The proposed study is designed for tea growing areas of Northeast India (Figure 1). The study area will be divided into six zones comprising of the tea areas namely Upper Assam, South Bank, North Bank, Cachar, Terai and Dooars. These are the major tea belts of India. The area is covered by forests, undulating terrains and also by hills and plains. Assam extends from 24^0 8’ N to 28^0 2’ N latitude and 89^0 42’ E to 96^0 E longitude while Terai and Dooars lie between latitudes 27° 5' N to 20° 9' N latitudes and 87° 59' E to 88° 56' E longitudes. Summers are hot and humid with temperature ranging from 25 – 35^0C while the winters are relatively cold at night but pleasant during the day with temperature ranging from 15 - 20^0C. Between June – August, the region also experiences the monsoon rains. The average annual rainfall of the region is around 2000mm.

The study will comprise of satellite data procured from NRSC, Hyderabad for monitoring and carrying out required analysis for the individual gardens. Time series data should be considered in order to monitor the different stages of replantation. The basic objective of taking different images is to monitor and assess the entire process of uprooting and replanting in tea gardens of specific areas. Subsequent soil surveys should be carried out at regular intervals and mapping of the areas should be done based on the available datasets and ground truths. Use of RADAR imagery would help in distinguishing between tea plants and shade trees as it has the capability to penetrate beyond clouds and canopy cover. In addition to monitoring of pests and disease infestations, drainage aspects should also needs to be considered. This entire approach would then give us a better understanding of the patterns observed in a tea ecosystem. This would then enable the planters to modify their current decision support system for effective management and strategic planning of the gardens.

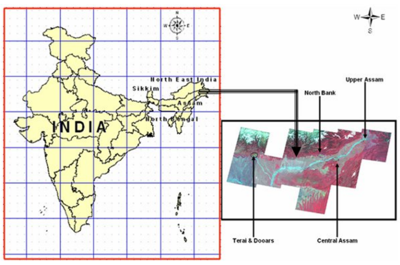

Figure 1: Study area where the proposed method could be implemented

Methodology

Generation of base maps: The base maps will include the study area boundaries, latitude and longitude of the area, road maps, contour maps, cadastral maps and attribute data. Individual garden maps should be collected for each zone at cadastral level. Every garden has garden maps with well demarcated sections and their coordinates. These garden maps could provide information like identifying the sections undergoing replantation with their section numbers and also the sections showing variations due to soil conditions and cultural practices.

Generation of thematic maps: Generation of DEM to observe the elevation of the area and its role is important in this study. Based on the existing contour maps and/or stereo satellite image, a DEM of the entire terrain could be generated, followed by the generation of slope and aspect maps since these factors (slope, elevation and aspect) have enormous importance to tea plants and also to soil conditions. These would then help the managers in effective decision-making. High resolution DEM at 30 m could be integrated and used for further analysis.

Satellite images: Space-based remote sensing due to its advantages of synoptic and repetitive coverage and providing data in a quantifiable manner has enabled the monitoring and assessment of natural resources and environment periodically and thus help decision makers to appropriately integrate the same with the other conventional inputs. IRS data has been extensively used in crop acreage estimation, ground water prospecting, cropping system analysis, precision farming, potential fishing zone identification, biodiversity characterisation at landscape level, desertification monitoring, wet land information generation, watershed development, urban area mapping, disaster management, flood monitoring, drought assessment and land slide hazard zonation etc.

Resourcesat-1 (IRS P6) with its varied sensors will add to our understanding in the above application areas. The data to be used for this study are the LISS IV (5.8m) and LISS III (23.5m). The ASTER (15m) data could also be used for monitoring purposes. ASTER products have characteristics such as classification of vegetables, grains, trees and pastures. It could be effectively used in monitoring tea areas due to its following characteristics such as measurement of planting and forest areas, crop yield estimation, monitoring of forest growth, investigation of soil health, investigation of human influence on the environment, mapping and monitoring and influence on environment due to natural disasters. CARTOSAT-2 (1m) could provide the capability to update the large scale maps to the levels of 1:4000 to 1:2500 scales. With these satellites, several applications like mapping the individual settlements, morphometric analysis of urban features, declination of water sheds and individual fields are possible. The image could be effectively used for delineation and characterisation of tea areas and their changes in the land use pattern. RADAR (30m) data can be used since it has the ability to penetrate through clouds and crop canopy, thereby avoiding shade tree interference. It could be fused with optical data and information could be extracted regarding the activities going on under shade trees. The above mentioned datasets could be effectively used for delineation of tea patches into different categories by applying various classification techniques like the sub-pixel classifier, segmentation-based classifier and fuzzy classifier. Large scale variations in the terrain properties that are relevant to tea bush could be studied through the use of remote sensing techniques.

Monitoring tea replantation/rejuvenation: Tea replantation is a stepwise process. There are eighteen steps that the replantation process has to undergo, starting from uprooting to fertilizer application to the young plants (Figure 2). The replantation process generally starts from the month of October in those sections where the plantations are more than 40 years old and where there is a decline in yield and quality of tea. During replantation, the tea plants are uprooted from the sections and the land is ploughed, followed by planting of Guatemala grass. After 18 – 24 months stand in the field, the Guatemala grasses are removed and the land is ploughed for new plantation followed by leveling and manuring. Once ready, the seedlings are planted from the nurseries.

This study aims to monitor Guatemala grass and detect the patterns relevant for tea bush. To carry out such a study, a multi-temporal image analysis needs to be performed. An image for the month of October will give the status of sections before uprooting, while an image of January will give the status of sections uprooted completely. An image for the month of June for the next year will show the Guatemala plantations, confirming that the process of soil rehabilitation has started. From this stage, at an interval of three months, satellite images can be used to detect patterns and extract information regarding the status of the section which would enable us to take effective measures as required. The pattern analysis can be done using wavelets. After the replantation process is completed and the patterns analysed, a problem specific fitness factor can be used to construct a fitness function to the feature space. This process would discover the patterns that would yield high fitness value. The temporal pattern that matches will then be observed through a thresholding process. This algorithm will help in identification of statistically significant temporal patterns in tea plantations.

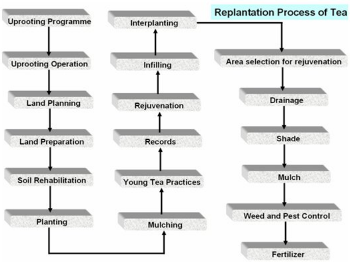

Figure 2: Diagram showing the different steps of replantation (Tea Research Association, Assam, India)

Image processing, reconnaissance and survey: Once the images are procured, they would be geometrically, radiometrically and atmospherically corrected and the noise in the images would be removed, followed by the generation of false colour composites (FCC) and its interpretation. The image interpretation will involve the identification of tea patches using shape, size, colour, tone, texture, etc. It will also involve monitoring of uprooted and replanted tea garden sections. The identified patches in the images require verification through visual interpretation and field visits which would involve visiting the area, identifying the patches, ground truthing and collecting relevant garden data for carrying out both image processing and statistical modelling.

Analysis: Different classification techniques would be involved (sub-pixel, fuzzy and segmentation based classifier) to delineate the tea patches into different categories. For the classification techniques, different datasets at different time periods should be used to classify the health status of tea patches in the area. The sub-pixel classification would help identify the mix classes within a single pixel. The fuzzy classification would help to characterise the complexities in the tea plantations. The analysis will divide the image data into various segments and then classify the segments by means of fuzzy-based approach. The fuzzy supervised classification used for mapping the tea areas with high resolution images like LISS IV or CARTOSAT-2 may provide high spectral seperability among different classes. By applying the fuzzy classification, vegetation heterogeneity and variability can be modelled if a relationship between fuzzy membership and percent cover can be reliably established. Improved classification accuracy and the potential to model vegetation structure and density will prove useful to the managers. This is especially true in areas where existing classifications do not adequately portray the complexity of vegetation found in the region. Field data can be used to build a reference dataset. The soil map and yield map generated using soil and yield data can be used to detect and analyse diseases, thereby assessing the crop damage. Further, the use of fuzzy technique would help in better understanding of the influence of various parameters like NDVI, textural data, etc. A soil moisture retrieval algorithm can be developed by combining parametric and non-parametric tools like maximum likelihood, fuzzy logic, etc. Qualitative and quantitative maps can be generated with different levels of accuracy. Crop and disease specific signatures can be used to observe and assess the damage to crops. Once the crop assessment is done, wavelets can be applied to detect changes in the time series data. The patterns analysis carried out can then help to identify, detect and assess changes in the datasets using various statistical techniques. Therefore, using the space-time analysis one can consider the effects of pests and diseases on tea bush health and its prediction of occurrence. This would then enable analysis of the interactions between pest and diseases in space and time using multivariate statistical modelling.

Leaf selection: The collected spectra will contain a large number of soil spectra that will be recorded together with the plant spectra. In order to consider the entire spectral signature of the canopy, it is very important to select only plant spectra and separate them from the soil spectra. The whole canopy has to be taken into consideration because the disease may occur in any direction in the tea plant. NDVI is a widely used parameter for leaf detection in presence of soil (Rouse et al., 1974). It is defined as follows:

$$NDVI = \frac{NIR - R}{NIR + R}$$

where, NIR is the near-infrared reflectance (740–760 nm) and R the red reflectance (620–640 nm). The spread of the NDVI over a plant (or an entire plot) characterizes the state of the plant (age, leaf area index and health to some extent).

Soil analysis: The successful mapping of soil moisture under vegetation canopies from active microwave data would be an advantage to agriculture, global climate change studies, water resource management and other areas. The dynamic range of soil moisture is generally affected by the variation in soil surface characteristics such as: soil texture, land cover, and vegetation parameters. Soil texture affects the microwave sensing of soil moisture through changes in the soil dielectric constant (via the relative amount of sand, silt, and clay in the soil). The land cover effect on the total back scatter received by the sensor is mainly due to the macro-structure of vegetation canopy such as height of canopy and number of plants or trees per unit area and the micro-structure. The behaviour of the soil can also be studied using space-time analysis. Based on different soil characteristics, soil patterns can be studied. Therefore, microwave remote sensing can play a very important role in determining the physical properties of soil. Microwave technology has the ability to quantitatively measure soil moisture under a variety of topographic and vegetation cover conditions, so potentially it could be extended to routine measurements from a satellite system (Engman and Chauhan, 1995).

A polarimetric SAR backscatter measurements, by using eigen values and eigenvectors of the covariance matrix, can be decomposed to into three components based on the scattering types - (1) an odd number of reflections, (2) an even number reflections, and (3) a cross-polarised scattering power. It can be written as: $T = \lambda_1 K_1 K_1^{*T} + \lambda_2 K_2 K_2^{*T} + \lambda_3 K_3 K_3^{*T} \quad \text{..............} (1)$

Where λ and K are eigen values and eigenvectors; * is a conjugate operator for a complex number and T is a transpose operator for a vector. The subscript 1, 2, and 3 represents the decomposed odd, even, and defuse components, respectively. This decomposition technique allows us to obtain the estimation of single and double reflection components of backscattering coefficients.

CUPPA Tea Model: The CUPPA Tea Model, developed by the University of Cranfield, UK should be used in all tea growing areas to see if the model could predict tea under Indian conditions. Using this model we can synthesise the large quantity of existing data on the yield responses of tea to climate and management factors, and to make the results accessible to advisers, managers and planners in the smallholder sector through the development of a model to predict yield potential and distribution in tea.

One of the uses of CUPPA-Tea is to estimate the potential yield for a particular area or region. Potential yield is defined as the yield that can be obtained when factors such as water shortage, nutrient limitations, and pests and diseases are not restricting the growth of the crop in any way (Matthews and Stephens, 1998 a,b,c). Only factors such as temperature, sunlight, day length, and clonal characteristics affect the potential yield. It is important for managers to know what the potential yield of a particular site is and its scope for improving the existing yields. In this so-called ‘yield-gap analysis’, if there is only a small difference between the predicted potential yield and what tea growers are achieving at present, then any resources spent in trying to improve yields are likely to be wasted. On the other hand, if there are large differences between potential and actual yields, then it is likely to be worthwhile to improve management in some way, provided that the factor(s) limiting the yields are correctly identified.

MODIS-NDVI analysis: The MODIS-based NDVI and LAI values can be used for yield estimation. An earlier study by Dutta, 2010, confirms that NDVI and tea LAI have a strong relationship. The same method should be applied to all tea growing areas to see the relationship between NDVI and LAI which would further help in effective yield monitoring of individual gardens.

Conclusion

Monitoring of tea plantations from time to time has become a pressing need. Statistical modelling and image mining could play an important role in monitoring the tea gardens from time to time. This proposed study will lead to improving the existing decision support system of tea management wherein all the information will help the management in making effective strategies for improving their tea gardens and the industry as a whole through constant monitoring thereby preventing the yield loss through quality production and increase in profitability. Scheduling of fertilizer, pesticide application and plucking will be generated. This will result in the development of a customised GIS package (Ghosh and Roy, 2004) that will help users have all their spatial and non-spatial information related to the estate and that in turn help the management to take decisions easily. The flow diagrams of the entire methodology are given in Figure 3 and 4.

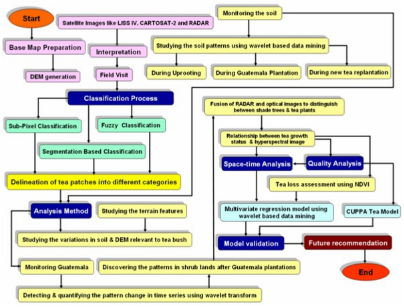

Figure 3: Flow diagram of the proposed methodology for plantation monitoring

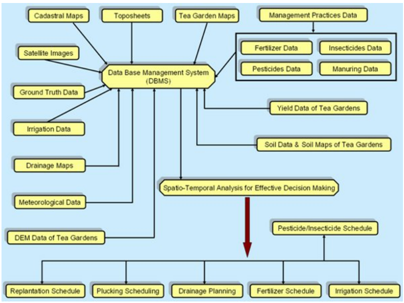

Figure 4: Modified flow diagram of an effective decision support system for the tea garden management for future strategies (Ghosh and Roy, 2004)

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