

Monitoring Tea Plantations in India Using Remote Sensing Approaches

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Key words: Remote Sensing, GIS, Wavelets, Pests, Monitoring, India

SUMMARY

Tea is one of the most important beverages in India and is a number one foreign exchange earner. India is the largest producer and consumer of tea in the world. Over the past few years, it was found that the tea industry is losing its ground mainly because of the wrong production mix, inability to compete with other tea producing countries due to high cost of production, organization of small holder farmers, poor quality control at the processing level, non replacement of aged plantations and also from pest's infestations. Therefore developing an approach for monitoring tea plantations at regular intervals using satellite based remote sensing and GIS has become a pressing need. In this study remote sensing techniques were applied to understand the affect of pest's infestations and waterlogging status of the tea plantations in North East India. Further efforts have also been made to see if patterns could be identified using wavelet based approaches in replanted sections of tea plantations. The study revealed that pests infested tea areas could be delineated using high resolution satellite data and also showed that waterlogging in tea plantations can be monitored from time to time using remote sensing. A wavelet based pattern analysis was also carried out and the results obtained showed that minor spatial changes can be extracted using frequency domain information. The study took into consideration different methods and approaches that could fit best in monitoring tea plantations from time to time.

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1. INTRODUCTION

India is the largest producer and consumer of tea in the world. Due to increasing competition from countries like Sri Lanka, Kenya, China, Bangladesh and Indonesia, and problems in maintaining the quality, Indian tea yield has been witnessing a downward trend. Yield statistics of tea showed that the plants starts yielding from third year onwards maintaining a steady increase in trend upto 20 or 30 years of age, within which they reach a peak in production and then decline. Over a past few years, it was found that the Indian tea industry is loosing it's ground mainly because of wrong production mix, inability to compete with other tea producing countries due to high cost of production, organization of small holder farmers, poor quality control at the processing level and more significantly from pests infestations. Most of the tea gardens have plantations which are more than 50 – 100 years old. Keeping in mind the current secnerio, monitoring the plantations through the use of remote sensing technology has become a pressing need.

Good tea productivity could be ensured if the plantations are monitored from time to time as well as detecting crop infestations at an early stage. Monitoring can be done effectively provided remote sensing imageries are made available on a frequent basis. Remote sensing has a number of attributes that lend themselves to monitoring tea bush health. High-resolution imagery and multispectral imaging capabilities should be used for detecting damage and monitoring stress. Further the images should be made available to the planters at the earliest possible time to take effective management decisions. Images are also required frequently at specific times during the growing season. A recurrent problem of tea gardens is pest infestation and most of the plantations are highly prone to Helopeltis, Red Spider and Lopper attacks. Using remote sensing such infestations can possibly be timely monitored and assessed (Dutta et al 2006).

In the North Eastern region of India, large tea plantations (about 350,000 ha) have of late become susceptible to continued water logging, droughts, soil erosion etc. in certain areas. Water follows through the catchment and hence the problem of drainage have to be addressed on the basis of a watershed (Bordoloi, et al, 1996). Thus topographic information is very essential to understand the existing drainage network in the region. For identifying exact nature of drainage problem and the geographic changes that have taken place over time, very strong and accurate diagnostic tools are required, which are difficult to find with the conventional analytical procedures (Bhagat et al., 2007). With the expansion of tea cultivation in India, it is observed that instead of facing high drainage problems, most of the gardens are now facing the problems of siltations blocking natural drainage systems (Bhagat et al 2009). Various researchers have reported the potential of optical and microwave remote sensing for waterlogging assessment (Agbu et al. 1990, Singh and Srivastav 1990, Choubay 1997).

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Except for microwave satellite image-based methods, most optical remote sensing image based studies have been based on the visual interpretation of the False Color Composite (FCC) of multispectral satellite data. However, the mapping of waterlogging areas by the classification of raw satellite data has several limitations when there is perennial vegetation cover (Rao et al 2006). Besides surface waterlogging, the tea plantations in the present study area also suffer with sub-surface waterlogging owing to the very high water table and the penetration of plant root to the extent of the water table. In the most severely affected areas, total crop failure can result in bare soil patches; in other severely affected areas, early crop development is retarded, resulting in a mixture of thin crop and water-tolerant weeds. The spectral reflectance from waterlogged crop pixels would be expected to contain a decreased contribution from the crop and an increased contribution from soil and weeds.

According to Kamau, 2008, he stated that old and degraded plantations should be replaced by high yielding clonal cultivars. As the tea plants stand on the same soil for more than 50 years, it was found that monoculture of tea for more than 50 years adversely affects soil quality (Barua 1969). Further studies have also showed that soil quality influences tea yield and quality (Kamau et al 2008). With the yield started to decline, the plants and the soils within the section are considered to be exhausted and the sections are considered to be ready for replantation. Information obtained from different possible statistical observations of remotely sensed data can be combined with collateral data in Geographic Information System (GIS) providing an insight to the cultural practice being followed in the cropping system (Dutta 2006). The integrated tools of remote sensing image processing and GIS technologies can aid in identifying not only those tea crops which are affected by the stress conditions due to weather related damage, excess or deficiencies of moisture or contamination and infestations but also phenological age of the plantation. The problems detected at an earlier stage, provides an opportunity to predict the situations for the planters and to ameliorate the effects by deciding upon the correct type and amount of fertilizer, pesticides and irrigation which can aid in improving the productivity and quality of the field in a cost effective manner (Singh et al 2009). In recent times wavelet analysis have been extensively used in various disciplines like the natural sciences (seismic events), engineering, astronomy (image processing), and medicine (ECG, medical imaging). From remote sensing perspective, wavelets are applied regularly for image classification, scaling dimensions (compression, band reduction in hyper spectral data), modelling multiscale phenomenon, denoising (SAR) and image fusion. It seems that there is no limit to the subjects where it can be used from signal processing to solution of statistics and partial differential equation (Resnikoff and Wells, 2000). Using wavelets one can view data at different scale hence it proves to be very useful in extracting the pattern revealed at different resolution.

Keeping this view in mind, a study was initiated in the North Eastern Region of India with the objective of monitoring and assessing the extent of water-logging in tea growing areas, delineation of pest infested tea areas and also identification of patterns observed from satellite data using wavelet based approaches.

2. MATERIALS AND METHODS

2.1. Study Area

The study was conducted in the North Eastern Region of India in parts of Assam and Dooars (Fig. 1).

Assam has an area of 78000 km². The state extends from 89° 42' E to 96° E longitude and 24° 8' N to 28° 2' N latitudes. The average annual temperature ranges between 30 and 35°C in summer and between 6 and 8°C in winter. An area of 3138 km² is covered by more than 800 tea plantations with an annual production of 480 million kgs and an average yield of 1534 kg ha⁻¹.

Dooars is located between 26° 30' N to 26° 56' N latitude and 88° 7' E to 88° 53' E longitude. The region has an area of 8800 km² and is located in the foothills of the eastern Himalayas bordering Bhutan. It has an altitude of 1750 m in the north and 90 m in the south. Summers are characterized by monsoon rains and the winters are cold and foggy. Average rainfall of the area is 3500 mm. Tea is the major industry in Dooars. According to Tea Board of India, Dooars has an area of 729 km² under tea plantation with an annual production of 142 million kg and an average annual yield of 1950 kg ha⁻¹ in 2007 (Tea Statistics 2007).

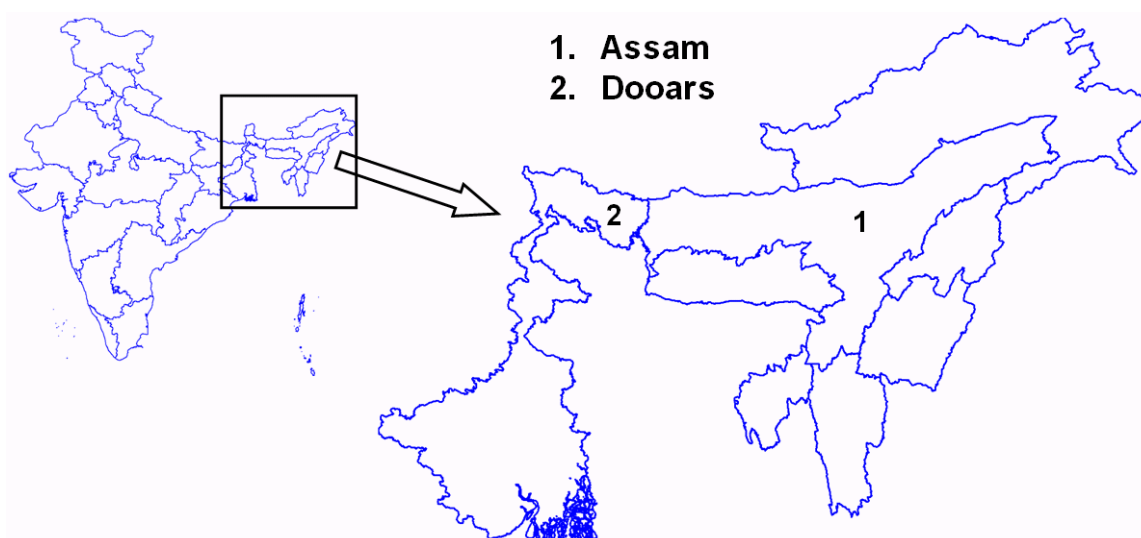


Fig. 1. Map showing Assam and Dooars Areas in India

2.2 Data Source

The main sources of data was LISS IV (5.8 m resolution) MONO, LISS III (23.5 m resolution) from RESOURCESAT1 (IRS P6), procured from National Remote Sensing Centre, Hyderabad, India. ASTER (15 m resolution) procured from ITC, The Netherlands, LANDSAT (30 m resolution) procured from the Global Land Cover Facility and some Google Earth images. The statistical data was collected from Tea Research Association and also from the individual gardens.

2.3 Methodology

2.3.1 Classification

Classification categorizes the pixels present in an image into different land cover classes. From an image, classes have to be distinguished and different spectral characteristics need to be considered. This is achieved by comparing different spectral reflectance curves. In classification, multispectral data are used and the spectral pattern within a pixel in an image is then categorized on a numerical basis (Lillesand and Kiefer, 1994). In this study, pixel based image analysis was carried out. Unsupervised classification was performed on ASTER, LISS III and LANDSAT images. The unknown pixels present in an image were then divided into a number of classes on the basis of natural groupings present in the image values. Unsupervised classification does not require analyst specified training data like supervised classification. Supervised classification was carried out and the land cover classes were generated using the training dataset. Once the classified maps were generated, the tea patches were delineated into healthy, moderately infested and infested tea patches and a qualitative analysis was done to find the percentage of area under healthy, moderately infested and infested tea patches. The formula used for estimating the percentage of infested and healthy tea is given below:

- **Healthy Tea Patches (%)** = *Area of Healthy Tea Patch / Total Tea Area*
- **Moderately Affected Tea Patches (%)** = *Area of Moderately Infested Tea / Total Tea Area*
- **Diseased Tea Patches (%)** = *Area of Infested Tea / Total Tea area*

Further a texture based classification was also carried out to see if tea patches could further be delineated into healthy, moderately infested and pests infested tea patches. The Grey level co-occurrence matrix technique was used to separate out the different tea patches. Different windows were used in the analysis such as 3x3, 5x5, 7x7, 9x9, 11x11, etc. but it was found that only 3 x 3 window gave good results with proper clarity. The other windows had to be rejected due to haziness. The band with best texture result was then selected for analysis purposes.

2.3.2 Delineating waterlogged tea areas

Further attempt was made to delineate the waterlogged tea areas. The administrative boundaries, contours etc. were digitized for the area under study. The digital elevation model (DEM) was generated from the interpolation of contour lines and spot heights. The LISS IV MONO image was geo-referenced with LISS III FCC geo-coded image. Using resolution merging technique, supervised classification was done by using the signatures collected from the base map of both the areas during ground truthing and landuse/land cover map was generated. Further unsupervised classification was also done. Sometimes supervised techniques seem inadequate because of complexity and heterogeneity of target feature, narrow cover type spectral separation and limited potential for automated classification (Bhagat et al 2009). The drainage maps were generated by digitizing the images and also by extracting the

Survey of India drainage system. It was later superimposed to identify change detection. A thorough ground survey was also done with the help of GPS. Field information like vegetation status, soil, topographic parameters were collected. Some spectral confusion encountered for some features - tea and dense shades within shaded areas, sand and gravel with non-irrigated dry land etc. were noticed, which are not unusual for this type of study. Using the field and the ground truth information, the classified maps were generated with an overall accuracy of 90 percent. Further visual and digital approaches were conjunctively used for the finalization of the maps.

2.3.3 Wavelet based pattern analysis

Wavelet represents the mathematical functions where the data is converted to different frequency components. It involves solving problems like signal cutting or limited precision in which windowing techniques are applied with a variable sized regions. It also provides a powerful framework for multiresolution images based on its spatial and frequency characteristics. Wavelets have been used specially in the fields of mathematics, electrical engineering, quantum physics and seismic geology. Interchanges between these fields have resulted in many wavelet applications such as compression, turbulence, radar, human vision and earthquake prediction.

High resolution Google data along with LISS III data was used for this study. To study the within field variations, LISS III data was fused with the high resolution CARTOSAT 1 data. The google earth image was georeferenced using the UTM projection. The geometric correction was done with the help of more than 30 ground control points (GCP's) collected from google earth and located accurately in the image. The image was resampled to assign the DN values to the transformed grid by using nearest neighbor (NN) interpolation algorithm, because NN preserves the spectral information of the original image. The fused image was then resampled to 2.5 m resolution. The primary goal of remote sensing is to identify and assess the pattern of vegetation distribution. Richardson et al. 1977, developed perpendicular distance to the soil line as a measure of vegetation development known as perpendicular vegetation index. Most commonly used vegetation index is NDVI (normalized differential vegetation index), but it requires near infra red and red spectral bands. In this study high spatial resolution of the fused image is obtained at the cost of spectral information of the image. So neither the fused image nor the Google image had the spectral information required for NDVI computation. So the analysis was carried out without the NIR spectral information since Google earth images were used. Taking the same soil line concept, a linear regression is drawn between the bands which better represents the vegetation against the band representing the pixels of bare soil. This distance based vegetation index is designed to detect the feature of vegetation cover and eliminate the background soil brightness. The digital elevation model (DEM) was generated from the CARTOSAT 1 stereo data. The image was radiometrically corrected and UTM projection was used. To improve the accuracy of the DEM, ground control points from the Google earth was used. Geostatistical analysis like correlation, cross correlation and anisotropic autocorrelation was used to study the spatial variability within the different fields.

Google earth data at 1m resolution and fused LISS III and Cartosat-1 data at 2.5 m spatial resolution was taken. These data did not have spectral information required for calculation of NDVI so PVI (Perpendicular Vegetation Index) was calculated as a greenness index. After performing the required pre-processing, the images of each stage of replantation were brought into the wavelet domain. The general characteristics of garden as well as the section under study were analyzed. The topographical and hydrological parameters were derived from Digital Elevation Model (DEM) generated from the stereo Cartosat data. Derived parameters were correlated and analyzed with the extracted pattern from wavelets. Analysis was supported by the ancillary information like soil and climate data collected from the tea gardens.

3. RESULTS AND DISCUSSIONS

3.1 Delineation of pests infested tea areas

Using the landuse/landcover maps, tea garden patches were masked out and the pest infested patches were delineated. The gradual spread of the infestation was then observed in the multi temporal data. The spread was seen between 2001 and 2004. It was observed that LANDSAT, LISS III and ASTER could separate out the tea patches into healthy, moderately infested and infested patches. The images at the three different dates were then compared and the spread was observed. The tea patches were then analyzed and the percentage of area under healthy, moderately infested and infested tea were calculated (Table 1). This shows that there has been a gradual spread of the infestation between 2001 – 2004.

Classes	LANDSAT Image		LISS III Image		ASTER Image	
	Area (Ha)	Area %	Area (Ha)	Area %	Area (Ha)	Area %
Healthy Tea Patches	12760	51.12	10718	42.93	6210	24.87
Moderately Infested Tea Patches	7841	31.41	9948	39.85	12496	50.05
Infested Tea Patches	4365	17.48	4300	17.22	6260	25.07
Sum	24966		24966		24966	

Table 1. Table showing the percentage of Healthy, Moderately Affected and Affected Tea Patches

The qualitative analysis showed a gradual reduction in the percentage of area under healthy tea. In December 2001, 51% of the area was under healthy tea followed by 43% in February, 2004 which further reduced to 25% in June, 2004. During June, 2004, the area under infested tea was almost 25% as compared to December, 2001 and February, 2004. From the analysis, it could be observed that the pest infestation was more dominant during the month of June. Hot and humid weather accompanied by frequent rainfall results in Helopeltis outbreak caused by Tea Mosquito Bug. Tea bushes are highly prone to helopeltis attack sometimes even resulting in severe damage to the sections.

Using the texture based classification, the tea patches were further classified into healthy, moderately infested and infested patches. Texture classification was applied to the different images using different texture windows like 3×3 , 5×5 , 7×7 , 9×9 , 11×11 , 13×13 , 15×15 , 17×17 and 19×19 . 3×3 window gave good texture results with proper clarity while the

other windows had to be rejected due to haziness. The band with good texture result in a 3×3 window was then analyzed.

Band 4 (NIR) and 5 (IR) gave good texture results for the LANDSAT. From parameter mean the tea patches could be separated out but large interclass mixing was observed for the other parameters. Using the mean results the healthy and infested patches were delineated. For the LISS III image, Band 3 (NIR) and Band 4 (MIR) gave good texture results from parameter mean. Healthy patches could be delineated but interclass mixing could be observed between the moderately infested and infested patches. So both these classes had to be grouped as infested tea patch. The three bands in ASTER gave good texture results, separating the three patches into healthy, moderately infested and infested tea patches. All the other parameters of texture classification had to be rejected because of excessive interclass mixing. (Fig. 2)

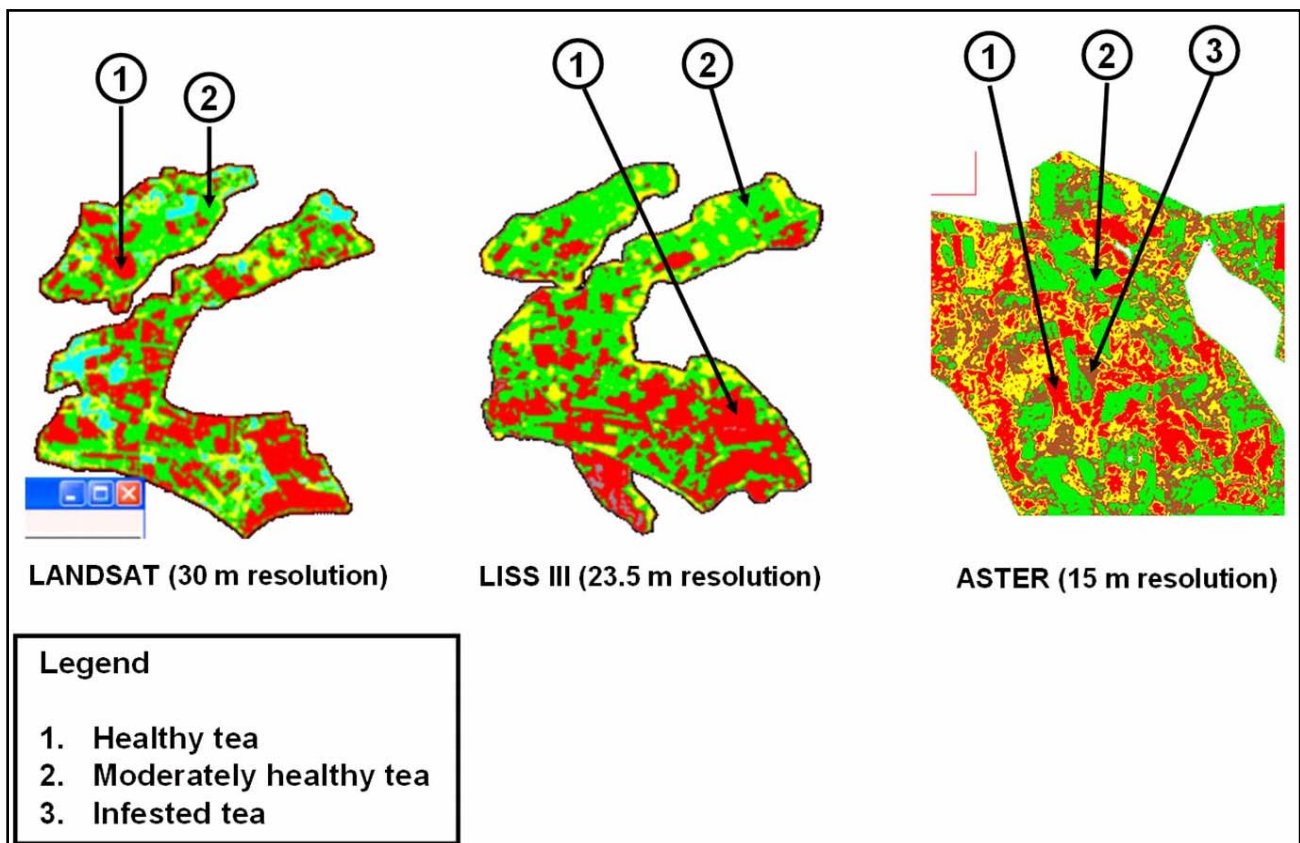


Fig. 2: Delineation of healthy and affected tea patches from texture classification in the different tea gardens of Assam, India

3.2 Delineation of waterlogged tea areas

The drainage layers were digitized using the Survey of India (SOI) topomap and satellite image of 1971 and 2004 respectively. Drainage layers were extracted from both the Survey of India (SOI) map (1971) and satellite image (2004). It was observed that most of the drainage in the SOI map has become extinct in the satellite image (Fig. 3 and 4). By correlating the

field data with the drainage maps, it was found that eutrofication and man made bunds, besides several new sub-divisions coming up as built up areas were the major causes of drainage extinction resulting in floods due to blackage of natural flow of water. Moreover, the dried drainage networks appearing in the image are also blocked by this problem and their natural flow was obstructed. In some gardens these are used as reservoirs and pumping is done to drain out excess water. In the Tingrai area of Assam, India, it was observed that majority of the flood and water logging problems are created largely due to blockage of free flow of water through natural channels. Also some of the channels have become extinct over the years due to non flow of water and some being diverted by the garden authorities.

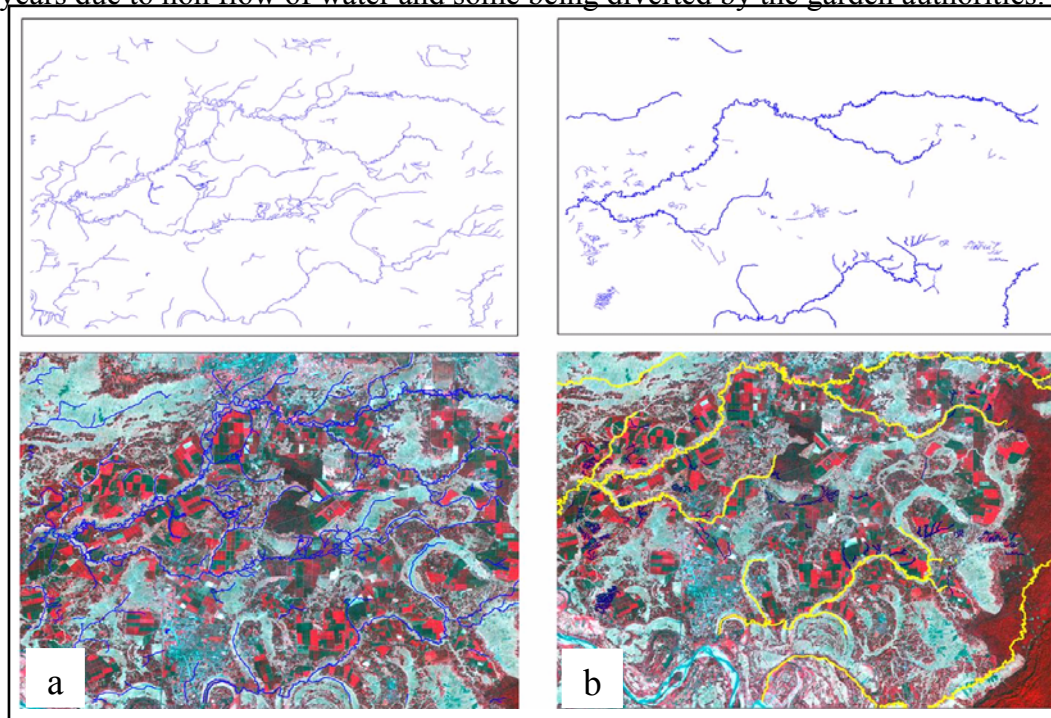


Fig. 3: Drainage status in (a) 1971 and (b) 2004



Fig. 4: Waterlogging as seen in one of the gardens in Tingrai basin of Assam, India

3.3 Monitoring tea replantation and identifying patterns

Patterns from an uprooted section were studied using wavelet based approaches. Immediately after uprooting of the section, the area is left open for 3 – 4 months to kill the micro-organisms present in the soil. Then the land is ploughed and is left open for another one or two months. At the same time, contour survey, identification of catchments, marking of drainage lines and filling up of unwanted drains and shade stump holes are done. Soil analysis is done to check the pH and the organic matter content in the soil. Sub-soiling is also done to provide proper aeration to the soil. To identify patterns, wavelets were applied and analyzed in the uprooted section, to see if patterns could be extracted. The work was carried out in the Dooars area of North East India.

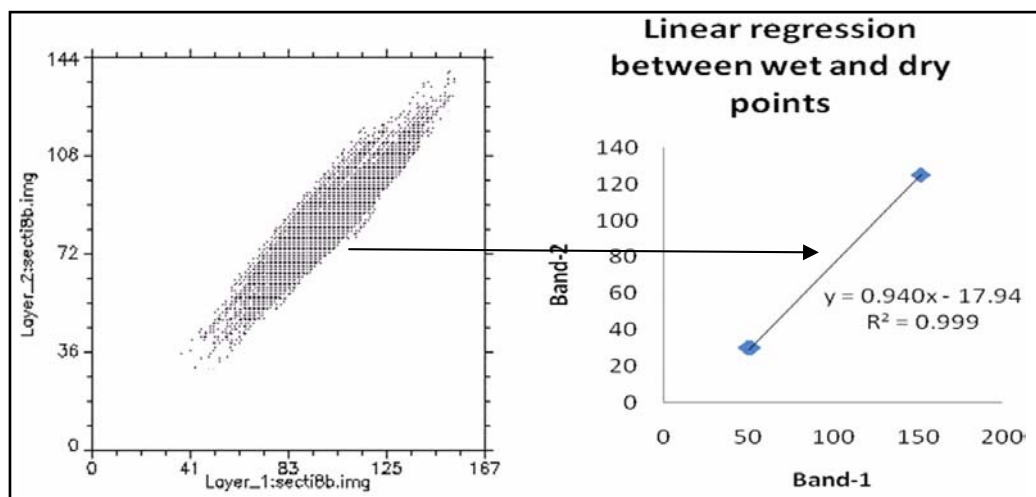


Fig. 5: Scatter plot between bands of max variation among vegetation and soil, and the regression line drawn between most wet and dry vegetation points

The section was bare with small patches of vegetation. The google earth image was used so NDVI (Normalised Differential Vegetation Index) could not be generated. Based on the concept of PVI (Perpendicular Vegetation Index), soil indexing was done using the set of spectral bands which shows highest variation between vegetation and soil. To calculate the PVI, linear regression line was drawn between the highest dry and wet vegetation points in the feature space. All other points were shifted on this regression slope line, by calculating the euclidean distance between the points and the perpendicular intercept to the regression line. Distance based soil index was designed to enhance the soil brightness (Fig. 5).

From Fig.6, it was observed that in the western part of the section ploughing and drainage lines could be seen which was not seen in the approximation image. The Digital elevation model of the section gives the impression that some central and northern parts were at higher elevation as compared to the other parts, as seen from the contour lines. The slope map shows that except red region, steepness of the slopes was less than 10%, which determines the speed of water flow and thus the velocity of material flowing down the slope or infiltrating into

soils, irrespective of the direction. Flow accumulation map determines the cumulative hydrological and natural drainage pattern of the section based on flow directions.

To describe the effects of topography on location and size of saturated moisture areas, the compound topographic index (CTI) was used (Moore et al. 1993). The wetness index was based on the slope gradient for runoff generation. Compound topographical index shows the level of wetness i.e. saturation in the soil. The image was acquired in December 2006, which had only one rainy day of 0.4 mm. Bright reflectance showed that there was no moisture in the field. Blue colour in the approximation map shows some vegetation. In the west of PVI approximation image, lowest wavelet coefficient value was observed, indicating that these parts had most healthy situation for vegetation growth.

The pattern in the section mainly followed the drainage line towards east. The section was found 11% correlated with DEM, 6% correlated with wetness index, 5% correlated with slope and 2.5% correlated with flow accumulation. The results also shows that the pattern of the field was very weakly correlated with the topographic parameters.

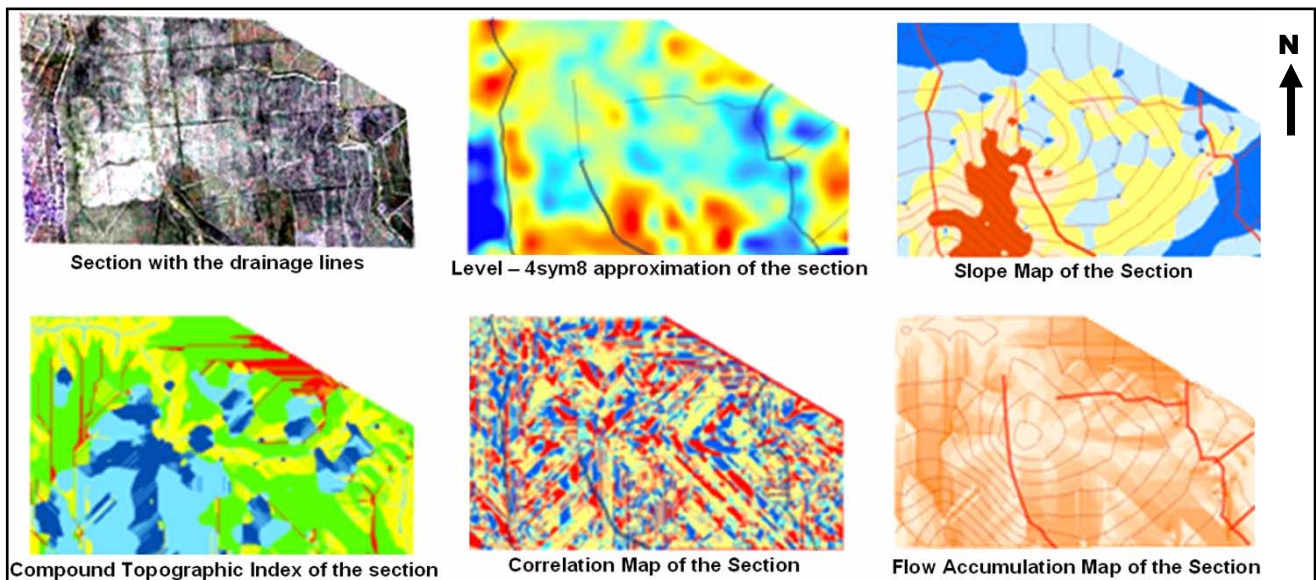


Fig. 6: Maps showing the approximation of the section, slope map, compound topographic index map and the flow accumulation map.

To visualize which part of the section gives better correlation with these parameters correlation map was generated and the mean and standard deviation of each 3×3 pixel sliding window was calculated. The generated correlation map between the extracted pattern with the DEM and Compound Topographic Index (CTI) are shown in Fig.6. Map shows that DEM was more correlated than CTI, but no specific area was found to be better explained by correlation map. Correlation can be considered as an evidence for a possible casual relationship, but it did not indicate the relationship prevailing there. Hence cross correlogram was drawn, which helps to evaluate the strength and direction of relationships between the variables, with their spatial aspect. Cross correlograms were also found informative in delineating the size of potential management zones for site specific harvesting (Kravchenko

and Bullock, 2002). The plot in Fig.7 shows that positive correlation exists between elevation and soil brightness, which gradually goes down to zero at 40 m distance and seems to be distributed normally.

Though correlation between the two variables was weak (nearly 11%), but their spatial correlation range was strong, which indicate that it will be easier to manage this relationship on a site specific basis. Typically cross correlograms has its maximum value at zero lag distance and gradually decreases until it becomes statistically insignificant. Correlation of slope with the soil brightness doesn't decrease much with lag distance, hence the relation was more stable than elevation.

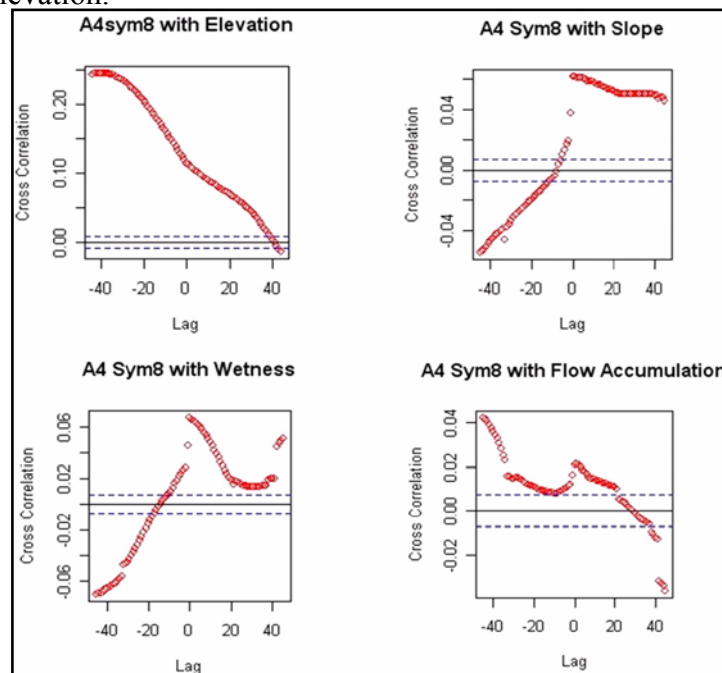


Fig. 7: Cross correlation plot of Selected level-4 approximation by sym8 wavelet with a. Elevation, b. Slope, c. Wetness Index and d. flow accumulation

Sedimentation and wetness shows their obvious relationship and had comparatively small range (nearly 20 m) of correlation, because the section was almost plane. Vegetation followed the drainage line (especially in the east), which indicates that management activities were the major driving force in a small section of 4.5 m height variation. Some central and southern part of the section have more soil reflectance as the moisture condition was low due to high elevation and low flow accumulation.

4. CONCLUSIONS

From the study we concluded that remote sensing can help in monitoring pests infestations in tea plantations. Further we could distinguish healthy, moderately infested and pest infested tea bushes using texture based classification. The study also showed that high resolution images like the ASTER could delineate the tea areas into healthy, moderately infested and pest infested areas. No interclass mixing was observed which was quite prominent in the LANDSAT and LISS III images. From this study we could not confirm that texture analysis

alone could give good results in delineating affected and non-affected tea patches unless it is compared with the results from different classification techniques. The study also showed that very high resolution data should be used to monitor the pest infested areas like the IKONOS, Quickbird and LISS IV (IRS P6 – RESOURCESAT). Further research should also involve different sensors for a comparative assessment or analysis.

To find the best suitable technique, knowledge and object based classification should be further explored and their results should be compared and assessed to find the best suitable technique.

The study also indicated that waterlogging problems in tea areas can be easily monitored by using a GIS platform. Blocking of natural drainage channels over the years by eutrophication, built up areas and siltation should be avoided. The problem could be solved by clearing the blocked drainage channels through governmental efforts and planters participation.

Wavelet provides more affluent warehouse for spatial analysis, as it operate locally and characterizes both low and high frequency resolution information simultaneously. But it was observed that the boundary pixel problem is one of the short comings of wavelets. Irregular shape of the field is a hindrance which was overcome by replacing the area with no data outside the study area by the image mean, to decrease the biasness due to abrupt change in frequency. Then images were decimated to filter variation at several spatial scales. Most suitable patterns were selected for each section by autocorrelation, which filters out constant values. The combination of both provides a better comparison for spatial analysis. The lower vegetation variability was generally associated with areas that have either steep surface or low flow accumulation. Cross correlation was carried out to evaluate the influence of hydrological processes that are related to vegetation, accurate Digital Elevation Model (DEM), drainage information and soil information like pH and organic carbon. No strong relationship was observed among them. The hydrological effects changing the vegetation pattern were not only guided by the relief and weather but also by the management strategies. The sections were of 10 – 13 hectares size with elevation of less than 4 meters and with proper drainage. No water logging was observed. So the variation in vegetation was difficult to analyze on the basis of topography.

It could be further recommended that high resolution and multitemporal multispectral images should be used extensively in this type of study to monitor the different phases of replantation. Extensive soil sampling is very essential along with their geospatial information to correlate soil properties with other spatial dataset. Proper drainage and management strategies should be adopted by the individual tea gardens. After extracting the patterns, field validation is very essential to identify the features on the ground which may be diseases or pests or waterlogging or any other problem.

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BIOGRAPHICAL NOTES

Rishiraj Dutta is a PhD student of the Department of Earth Observation Science at the International Institute for Geoinformation Science and Earth Observation, ITC, The Netherlands. Born on 4th August, 1980, he completed his graduations from Assam Agricultural University, Jorhat, Assam, India during the year 2003 with specialization in Agricultural Statistics. He then joined as an Officer Trainee at the Indian Institute of Remote Sensing (National Remote Sensing Centre), Indian Space Research Organization, Dehradun, India in the year 2004 for his post graduate studies. He obtained his master's degree in Geoinformation Science and Earth Observation with specialization in Geoinformatics under the joint MSc programme of Indian Institute of Remote Sensing (IIRS), Dehradun and ITC, The Netherlands in the year 2006.

During the same year, he joined as a Consultant in the Department of Natural Resources Management at the International Water Management Institute (Consultative Group of International Agricultural Research, CGIAR), Colombo, Sri Lanka and worked on the Global Irrigated Area Mapping (GIAM) Project as an Indian Partner for GIAM. From 2007 onwards, he joined as a PhD student in the Department of Earth Observation Science, ITC, The Netherlands and is currently working on the topic “Image Mining for Monitoring Tea Replantation and Assessing Environmental Factors Influencing Tea Quality.” The PhD is a joint programme between ITC, The Netherlands, IIRS, Dehradun and Tea Research Association (TRA), Jorhat, Assam, India. Rishiraj has good experience working with image processing software's like ERDAS, ENVI and GIS software like ArcGIS. He has a good knowledge of handling LANDSAT, ASTER, IRS, and MODIS data.

Further he would like to dedicate this work to his dearest late mother and his beloved Tamu who is always close to his heart.

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