

**Assessment of Tea Bush Health and Yield
Using Geospatial Techniques
STUDY AREA: SONITPUR DISTRICT OF ASSAM, INDIA**

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Assessment of Tea Bush Health and Yield Using Geospatial Techniques

by

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Abstract

Tea is one of the most important beverage in India. It is the number one foreign exchange earner. India is the largest producer of tea in the world. The Indian states of Assam, Meghalaya, Tripura, North Bengal (Darjeeling) and Sikkim contribute significantly to the overall tea production in the country. Apart from those, South Indian states of Tamil Nadu, Karnataka and Kerala also contribute to the production of tea.

Over a past few years, it was found that the tea industry is loosing it's ground. This is 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 and disease infestations.

Remote sensing and GIS technologies has been efficiently used for monitoring several annual crops like rice, wheat, etc. Therefore, developing an approach for monitoring tea plantations using remote sensing and GIS has become a pressing need. The lack of previous studies in monitoring tea using remote sensing provided the idea to develop an approach that can aid in monitoring the growth of plantations and help in taking effective measures when the need arises.

In this study, an attempt has been made to assess the tea bush health using texture and tonal variations from remotely sensed images. The Grey Level Co-occurrence Matrix (GLCM) technique was applied to categorize the tea patches into healthy, moderately healthy and diseased tea. The diseased patches were delineated using both texture and the classified images. The percentage of healthy, moderately healthy and diseased tea was derived. It was observed that LANDSAT image of December, 2001 showed 60.4% area under healthy tea, 23.6% area under moderately affected tea and 16.2% area under diseased tea. For the LISS III image of February, 2004, it was found that 43.9% area under healthy tea, 36.8% area under moderately affected tea and 19.3% area under diseased tea. Similarly for ASTER image of June, 2004, area under healthy tea was found to be 24.9%, moderately healthy tea was found to be 50.1% and diseased tea to be 25.1%. The results were finally compared with the ground Leaf Area Index (LAI) and the yield. Thus the texture analysis and tonal variations attempted here could play an important role in identifying and detecting disease patches in tea plantations.

Further to test whether MODIS derived NDVI is related to LAI, an empirical equation was established which shows that LAI in tea had significant and linear relationship with NDVI ($R^2=0.36$). This study showed that MODIS based NDVI during April, June and August was significantly correlated to tea leaf yield at estate level. However it was found that NDVI observation at different time period alone could not explained much variance in tea leaf yield. This shows that statistical model for tea yield does not seem to be encouraging.

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Dedicated to my Parents

“Parents can only give good advice or put them on the right paths, but the final forming of a person's character lies in their own hands”.

ANNE FRANK

Table of contents

I.	Abstract	
II.	Acknowledgement	
1.	Introduction.....	1
1.1.	Background of tea	1
1.2.	Need for Crop Monitoring	2
1.3.	Need for Crop Yield Forecasting	3
1.4.	Yield Estimation in India.....	4
1.5.	Economic Impacts of Remote Sensing and GIS in Tea Sector:.....	4
1.5.1.	Symptoms of <i>Helopeltis</i> and it's affect on the garden:	5
1.5.2.	Symptoms of <i>Red Spider Mite</i> attack and it's affect on the gardens:	5
1.6.	Problem Statement.....	7
1.7.	Motivation.....	7
1.8.	Objectives.....	7
1.9.	Research Questions	7
2.	Literature Review	8
2.1.	Optical Remote Sensing for Crop Monitoring:	8
2.2.	Remote Sensing of Leaf Area Index (LAI).....	8
2.3.	NDVI-LAI Relationship.....	9
2.4.	Application of Remote Sensing in Tea Sector:.....	9
3.	Study Area.....	12
3.1.	Study Area.....	12
3.1.1.	Location.....	12
3.1.2.	Population	13
3.1.3.	Climate	13
3.1.4.	Economy.....	13
4.	Materials And Methods	14
4.1.	Materials	14
4.1.1.	Remote Sensing Data	14
4.1.2.	Earth Observation Data:.....	14
4.1.3.	Field Survey Data:	15
4.1.4.	Software's Used.....	16
4.1.5.	Other Instruments Used.....	16
4.2.	Data Preparation:.....	16
4.2.1.	Georeference of the Data:.....	16
4.2.2.	Geometric Correction of Remote Sensing Data:.....	16
4.2.3.	Visual Interpretation of The Images	17
4.2.4.	Spectral Signature Analysis of The Optical Data:	18
4.2.5.	Processing of the Images	19
4.2.6.	Image Classification.....	19
4.2.7.	Texture Analysis.....	21

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

4.2.8.	Normalized Difference Vegetation Index.....	24
4.2.9.	Leaf Area Index (LAI).....	24
4.2.10.	NDVI-LAI Relationship.....	26
4.2.11.	Statistical Analysis	26
5.	Results and Discussions	29
5.1.	Visual Interpretation of The Images.....	29
5.2.	Results of Spectral Signature Analysis of the Optical Data (LANDSAT, LISS III and ASTER).....	29
5.3.	Digital Image Analysis	31
5.3.1.	Results of Supervised Classification of LANDSAT Image.....	31
5.3.2.	Results of Supervised Classification of LISS III Image.....	32
5.3.3.	Results of Supervised Classification of ASTER Image	32
5.3.4.	Quantitative Evaluation of Supervised Classification of the Images	33
5.4.	Delineation of Diseased Tea Patches	34
5.5.	Identification of Diseased Tea Patches Using Texture Analysis	36
5.5.1.	Results of Texture Analysis	36
5.6.	Comparison between Field Leaf Area Index (LAI), Texture Images and Yield	42
5.7.	A Qualitative Evaluation of The Percentage of Healthy, Moderately Healthy and Diseased Tea Areas	46
5.8.	Detection of Affected Plantations from Remotely Sensed Images.....	46
5.9.	Yield Estimation.....	47
5.9.1.	LAI Field Observations	47
5.9.2.	LAI and NDVI Relationship	47
5.9.3.	Relation Between Tea Leaf Yield and MODIS NDVI	47
5.9.4.	Tea Yield Model.....	48
6.	Conclusions and Recommendations.....	51
6.1.	Research Questions Concerning The Research Objective 1.....	51
6.1.1.	Research Questions	51
6.2.	Research Questions Concerning The Objective 2.....	53
6.2.1.	Research Questions	53
6.3.	Limitations.....	53
6.4.	Recommendation	54
7.	References	55
	Annexure	60
	Annexure 1: Softwares Used	60
	Annexure 2:.....	61
	Annexure 3: Yield of The Gardens	62
	Annexure 4: Table Showing The Error Matrix for LANDSAT, LISS III and ASTER	63
	Annexure 5: Graphs Showing The Yield Trend of the Gardens	65
	Annexure 6:.....	66
	Annexure 7: NDVI – LAI Relationship	67
	Annexure 8: NDVI & Yield Values Used for Tea Model.....	68
	Annexure 9: NDVI Images.....	69

List of figures

Figure 1: A tea garden patch affected by Helopeltis	5
Figure 2: Leaves damaged by Red Spider (TRA Lab)	6
Figure 3: Red Spider Mites Figure 4: Damaged leaf of a Red Spider Mite	6
Figure 5: A Garden Patch Showing Both Helopeltis and Red Spider Mite Attack.....	6
Figure 6: LANDSAT ETM+ showing the tea garden patches	12
Figure 7: (Sonitpur District of Assam, LANDSAT ETM+ (December, 2001).....	17
Figure 8: Spectral information in the image (Janssen, 2001).....	18
Figure 9: Spectral Reflectance of Healthy Vegetation.....	19
Figure 10: LANDSAT Image Showing the Garden Boundaries.....	19
Figure 11: LANDSAT Image Showing the LAI of a Healthy Patch	26
Figure 12: Methodology	28
Figure 13: (Sonitpur District of Assam, LANDSAT ETM+ (December, 2001)	29
Figure 14: Graph Showing The Landcover Class Seperability in LANDSAT ETM+	30
Figure 15: Graph Showing The Landcover Class Seperability in LISS III	30
Figure 16: Graph Showing The Landcover Class Seperability in ASTER.....	30
Figure 17: Landuse/Landcover Map of Sonitpur District (LANDSAT ETM+, December 2001)	31
Figure 18: Landuse/Landcover Map of Sonitpur District (LISS III, February 2004).....	32
Figure 19: Landuse/Landcover Map of Sonitpur District (ASTER, June 2004).....	32
Figure 20: Map Showing Merged Gardens (ASTER, June 2004)	34
Figure 21: Diseased Tea Patches.....	34
Figure 22: Diseased Tea Patches.....	35
Figure 23: Diseased Tea Patches.....	34
Figure 24: Shift in The Diseases As Seen The Temporal Images	35
Figure 25: Step I of Texture Analysis	36
Figure 26: Step II of Texture Analysis.....	37
Figure 27: Texture Image (LANDSAT, Dec. 2001).....	37
Figure 28: LANDSAT Classified Image.....	38
Figure 29: LANDSAT Image showing the Classified Textured Image of Monabarrie Tea Estate	37
Figure 30: Variance Image	37
Figure 31: Variance Image (Thresholded).....	38
Figure 32: Contrast Image	38
Figure 33: Contrast Image (Thresholded).....	39
Figure 34: Dissimilarity Image.....	38
Figure 35: Dissimilarity Image (Thresholded).....	39
Figure 36: Texture Image (LISS III, Feb. 2004)	39
Figure 37: LISS III Classified Image	40
Figure 38: LISS III Image showing the Classified Textured Image of Monabarrie Tea Estate	39
Figure 39: Variance Image	39
Figure 40: Variance Image (Thresholded).....	40

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

Figure 41: Contrast Image	40
Figure 42: Contrast Image (Thresholded).....	41
Figure 43: Dissimilarity Image.....	40
Figure 44: Dissimilarity Image (Thresholded).....	41
Figure 45: Texture Image (ASTER, June 2004).....	40
Figure 46: ASTER Classified Image.....	42
Figure 47: Variance Image	41
Figure 48: Variance Image (Thresholded).....	42
Figure 49: Contrast Image	41
Figure 50: Contrast Image (Thresholded).....	42
Figure 51: Dissimilarity Image.....	41
Figure 52: Dissimilarity Image (Thresholded).....	42
Figure 53: Entropy.....	42
Figure 54: Second's Moment.....	43
Figure 55: Correlation.....	43
Figure 56: Boundary of Tarajulie Tea Estate and the Field LAI Values Overlaid Over the Texture Image ..	42
Figure 57: Yield Trend of Tarajulie Tea Estate for Last 10 Tears	43
Figure 58: Boundary of Nahorani Tea Estate and the Field LAI Values Overlaid on the Textural Image	43
Figure 59: Yield Trend of Nahorani Tea Estate for Last 10 Years.....	44
Figure 60: Boundary of Monabarrie Tea Estate and the Field LAI Values Overlaid Over the Texture Image	44
Figure 61: Yield Trend of Monabarrie Tea Estate for Last 10 Tears.....	45
Figure 62: LAI-NDVI Relationship	47
Figure 63: MODIS NDVI Map With The Garden Boundaries	49
Figure 64: LANDSAT image showing the affected and healthy patches of tea gardens	50
Figure 65: LISS III image showing the garden patches	50
Figure 66: ASTER Image Showing The Tea Garden Patches.....	50

List of tables

Table 1: <i>Source: Indian Tea Association</i>	2
Table 2: <i>Source: Indian Tea Association</i>	2
Table 3: <i>Nominal Characteristics of Aster Image</i>	14
Table 4: <i>Overview of the nominal characteristics of Landsat-ETM+</i>	14
Table 5: <i>Nominal Characteristics of Aster Image</i>	15
Table 6: <i>Accuracy Assessment</i>	33
Table 7: <i>Table showing the Accuracy Results of the LANDSAT, LISS III and ASTER Images</i>	33
Table 8: <i>Table showing the percentage of Affected and Non-Affected Tea Patches</i>	46
Table 9: <i>Year wise correlation between tea leaf yield and MODIS based NDVI of tea estates during different months</i>	48
Table 10: <i>Tea Leaf Yield Models Based on MODIS NDVI</i>	48
Table 11: <i>Showing the Temperature (2000-2004) in °C</i>	61
Table 12: <i>Showing the Humidity (2000-2004) in %</i>	61
Table 13: <i>Showing the Rainfall in mm</i>	61
Table 14: <i>Table Showing the Yield of Gardens</i>	62
Table 15: <i>Error Matrix for LANDSAT ETM+</i>	63
Table 16: <i>Error Matrix for LISS III</i>	63
Table 17: <i>Error Matrix for ASTER</i>	64
Table 18: <i>Table Showing NDVI – LAI Extraction</i>	67
Table 19: <i>Table Showing Yield of the Gardens</i>	68
Table 20: <i>Table Showing the NDVI Values of the Gardens</i>	68

1. Introduction

Tea drinking originated in China and the word tea is derived from t'e of the Chinese Fukien dialect. The Dutch introduced it to Europe. In Cantonese, tea is known as Ch'a and this is the name by which this wonderful beverage came to be known in Japan, India, Russia, Iran and the Middle East. The first authentic reference to tea was made in an ancient Chinese dictionary revised by Kuo P'o, a celebrated Chinese scholar in AD 350. The first exclusive book on tea, Ch'a Ching meaning 'Tea classic' by the Chinese tea expert Lu Yu was published in AD 780 in which he has described various kinds of tea, their cultivation and manufacturing in China. The opening of a sea route to India and the East by the Portuguese in 1497 facilitated large-scale trading between Europe and the Oriental countries.

1.1. Background of tea

Tea is indigenous to India and is an area where the country can take a lot of pride. This is mainly because of its pre-eminence as a foreign exchange earner and its contributions to the country's GNP. In all aspects of tea production, consumption and export, India has emerged to be the world leader, mainly because it accounts for 31% of global production. It is perhaps the only industry where India has retained its leadership over the last 150 years. Tea production in India has a very interesting history to it. The range of tea offered by India - from the original Orthodox to CTC and Green Tea, from the aroma and flavour of Darjeeling Tea to the strong Assam and Nilgiri Tea- remains unparalleled in the world.

Here are some statistical facts about the Indian Tea Industry:

- The total turnover of the tea industry is around Rs. 10,000 crores.
- Since independence tea production has grown over 250%, while land area has just grown by 40%.
- There has been a considerable increase in export too in the past few years.
- Total net foreign exchange earned per annum is around Rs. 1847 crores.
- The labour intensive tea industry directly employs over 1.1 million workers and generates income for another 10 million people approximately. Women constitute 50% of the workforce.

The Indian tea industry is in a consolidation phase. Most branded tea players owning plantations have been looking at divesting their plantation so as to focus on branding and marketing. India continues to be the world's largest producer and consumer of tea. Domestic productions as well as exports have been on a rise. However, due to stiff competition from countries like Sri Lanka, Kenya, China, Bangladesh and Indonesia, and issues of quality, realizations on Indian teas have been witnessing a downward trend.

India's tea production increased by 17.7% yoy to 149.8mn kg during Jan-Apr 2005. Production in both the northern (up 23.7%) and southern (up 8.8%) regions witnessed an upward trend. During the same period, total tea exports from India in volume terms grew by 7.5% yoy to 149.8mn kg. Exports from southern region grew sharply by 25.4% yoy however, northern region registered a degrowth of 12.6% yoy in tea exports. Domestic prices (Kolkata auctions) during May 2005 registered a decline of 5.6% yoy (8.9% mom) to Rs72.9 per kg from Rs77.2 per kg in May 2004.

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

Tea production and exports

(mn kg)	Jan-Apr 2005		Jan-Apr 2004		yoy %	
	Production	Exports	Production	Exports	Production	Exports
North India	94.1	20.2	76.1	23.1	23.7	(12.6)
South India	55.7	32.6	51.2	26.0	8.8	25.4
All India	149.8	52.8	127.3	49.1	17.7	7.5

Table 1: Source: Indian Tea Association

Exports

India is the largest producer of tea and ranks fourth in terms of total tea exporters in the world. Total world tea exports grew by 4.4% yoy to 230.2mn kg during Jan-Apr 2005. Indian exports in value terms grew by 7.8% yoy to Rs. 4.6bn during Jan-Apr 2005. Exports from Southern region registered a strong growth of 26.9% yoy at Rs. 2.1bn while exports from Northern region declined by 4.7% yoy to RS2.4bn.

(Rs mn)	Jan-Apr 05	Jan-Apr 04	yoy (%)
North India	2,448	2,568	(4.7)
South India	2,136	1,684	26.9
All India	4,585	4,252	7.8

Table 2: Source: Indian Tea Association

1.2. Need for Crop Monitoring

Remote sensing offers an efficient and reliable means of collecting the information required, in order to map tea type and acreage. Remote sensing provides the structure information on the health of the vegetation. 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 the multispectral sensors. Information from remotely sensed data can be inputted to a Geographic Information System (GIS) and other cropping system which can then be combined with ancillary data to provide information of ownership and management practices, etc.

Assessment of tea health, as well as early detection of the crop infestations, is critical in ensuring good tea productivity. Stress associated with, for example, moisture deficiencies, insects, fungal and weed infestations, must be detected early enough to provide an opportunity for the planters to mitigate. This process requires that remote sensing imagery be provided on a frequent basis (at a minimum, weekly) and be delivered to the farmer quickly, usually within 2 days. There are also instances where the tea growth varies from one spot to another. These growth differences may be due to soil nutrient deficiencies and other stress conditions. Remote sensing allows the farmer to identify areas within a field which are experiencing difficulties, so that he can apply, for instance, the correct type and amount of fertilizer, pesticide or herbicide. Using this approach, the farmer not only improves the productivity from his land, but also reduces his farm input costs and minimizes environmental impacts.

Remote sensing has a number of attributes that lend themselves to monitoring the health of tea plants. One advantage of optical (VIR) sensing is that it can see beyond the visible wavelengths into the infrared, where wavelengths are highly sensitive to crop vigour as well as crop stress and crop damage. Remote

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

sensing imagery also gives the required spatial overview of the land. Recent advances in communication and technology allow a planter to observe images of his fields and make timely decisions about managing the crops. Remote sensing can aid in identifying the tea crops affected by conditions that are too dry or wet, affected by insect, weed or fungal infestations or weather related damage. Images can be obtained throughout the growing season to not only detect problems, but also to monitor the success of the treatment.

Healthy vegetation contains large quantities of chlorophyll, the substance that gives most vegetation its distinctive green colour. In referring to healthy tea crops, reflectance in the blue and red parts of the spectrum is low since chlorophyll absorbs this energy. In contrast, reflectance in the green and near-infrared spectral regions is high. Stressed or damaged crops experience a decrease in chlorophyll content and changes to the internal leaf structure. The reduction in chlorophyll content results in a decrease in reflectance in the green region and internal leaf damage results in a decrease in near-infrared reflectance. These reductions in green and infrared reflectance provide early detection of crop stress. 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 normalized 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. Phenology and vigour are the main factors in affecting NDVI. Examining 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 crop areas. If the data is georeferenced, and if the planter has a GPS (Global Positioning System) unit, he can find the exact area of the problem very quickly, by matching the coordinates of his location to that on the image.

Detecting damage and monitoring tea crop health requires high-resolution imagery and multispectral imaging capabilities. One of the most critical factors in making imagery useful to planters is a quick turnaround time from data acquisition to distribution of crop information. Receiving an image that reflects crop conditions of two weeks earlier neither help real time management nor damage mitigation. Images are also required at specific times during the growing season, and on a frequent basis.

1.3. Need for Crop Yield Forecasting

Forecasting crop yield well before harvest is crucial especially in regions characterized by climatic uncertainties. This enables planners and decision makers to predict how much to import in case of shortfall or to export in case of surplus. It also enables governments to put in place strategic contingency plans. Therefore, monitoring of crop development and of crop growth, and early yield prediction are generally important. Crop yield estimation in many countries is based on conventional techniques of data collection for crop and yield estimation based on ground-based field visits and reports. Such reports are often subjective, costly, time consuming and are prone to large errors, leading to poor crop yield assessment and crop area estimations (Reynolds *et al.* 2000). In some countries weather data are also used (de Wit & Boogaard 2001, Liu & Kogan 2002) and models based on weather parameters have been developed. This approach is associated with a number of problems including the spatial distribution of the weather station, incomplete and/or unavailable timely weather data, and weather observations that do not adequately represent the diversity of weather over the large areas where crops are grown (Dadhwall & Ray 2000, de Wit & Boogaard 2001, Liu & Kogan 2002, Rugege 2002). Objective, standardized and possibly cheaper/faster methods that can be used for crop growth monitoring and early crop yield estimation are imperative. Many empirical models have been developed to try and estimate yield before harvesting. However, most of the methods require data that are not easily available. The models complexity, their data demand, and methods of analysis, render these models unpractical, especially at field level. With the development of satellites, remote sensing images provide access to spatial information at global scale; of features and phenomena on earth on an almost real-time basis. They have the potential not only in identifying crop classes but also of estimating crop yield (Mohd *et al.* 1994); they can identify and provide information on spatial variability and permit more efficiency in field scouting (Schuler 2002). Remote sensing could therefore be used for crop growth monitoring and yield estimation.

1.4. Yield Estimation in India

India underwent a series of successful agricultural revolutions, starting with the "green" revolution in wheat and rice in the 1970s, the "white" revolution in milk and, in the 1980s, the "yellow" revolution in oil seeds. Despite these major transformations, the agricultural sector continues to be dominated by a large number of small landholders (70 % of rural people and 8 % of urban household depend on agriculture). The country is also marked by large fluctuations in agricultural output, though to a declining extent with the development of irrigation facilities, adoption of new technologies and changes in cropping patterns (FAO 2000a). The traditional approach of crop estimation in India involves complete enumeration (except in a few states where sample surveys are employed) for estimating crop acreage and sample surveys based on crop cutting experiments (CCE) for estimating crop yield. The crop acreage and corresponding yield estimate data are used to obtain production estimates. These yield surveys are extensive; plot yield data being collected using stratified multistage random sampling techniques (Government of India 2002, Singh *et al.* 1992, Singh *et al.* 2002). Although the approach is fairly comprehensive and reliable, the cost is more and the accuracy and timeliness of crop production statistics needs to be improved. Yield estimates predicted before actual production are required for taking various policy decisions. Hence, early assessment of crop yield is necessary, particularly in countries that depend on agriculture as their main source of economy. With the successful launching of satellites, remote sensing can play a vital role in the yield estimation process. To achieve timely and accurate information on the status of crops and crop yield, there is need to have an up-to-date crop monitoring system that provides accurate information on yield estimates way before the harvesting period. The earlier and more reliable information the greater the value (Hamar *et al.* 1996, Reynolds *et al.* 2000). Remote sensing data has the potential and the capacity to achieve this. Prediction and estimation of yield is closely related to the capability of identifying crop species and certain agronomic variables such as maturity, density, vigour, and disease which can be used as yield indicators (Nualchawee, 1984). The use of remotely sensed data in crop acreage estimation has been demonstrated by various researchers in different parts of the world (Saha and Jonna, 1994). Satellite data are complementary to data from GIS, Global Positioning System (GPS), yields monitor, and pencilled notes on the back of envelopes. Data from all sources should be brought together to give the grower the best opportunity to maximize yield and quality (Arvik, 1997). Tea yield is influenced by a large number of factors such as crop genotype, soil characteristics, cultural practices, weather conditions and biotic influences, such as weeds, diseases and pests. Two approaches adopted for yield modelling are remotely sensed data or derived parameters that are directly related to yield, and the others is remotely sensed data that are used to estimate some of the biometrics parameters, which in turn are input parameters to a yield model. Geographic information system can handle, manipulate and analyze data from different sources and coordinate systems, scales and formats (Navalgund, 1994). Remote sensing and crop growth simulation models have become increasingly recognized as potential tools for growth monitoring and yield estimation (Bauman, 1992). In the last few years, attention has been paid towards using satellite remote sensing data in tea crop estimation surveys, in view of its advantages over traditional procedures in terms of cost effectiveness and timeliness in the availability of information over larger areas. Murthy *et al.* (1995) reported the validity of crop yield models with satellite derived normalized difference vegetation index (NDVI) determined by the strength of association between the two variables including the model.

1.5. Economic Impacts of Remote Sensing and GIS in Tea Sector:

The benefits from using RS and GIS technology depend on the level of success of its application for solving a concrete task. In general, these benefits can be divided into four categories such as scientific, technological, methodological, and economic efficiency (Badarch, 1990). The scientific efficiency of remotely sensed data also includes obtaining new facts for corroboration and quantitative clarification of previously known, qualitatively studied data. Technological efficiency means increasing of the work productivity (mainly the most expensive field job), making norms for fieldwork and speeding up the process of tea mapping, reducing the fieldwork volume, shortening the time necessary for surveys and reducing the number of personnel engaged in tea garden surveys. Methodological efficiency means increasing the accuracy and detail of spatial research of tea resources and also of observing widespread and dynamic processes and phenomena. Finally, economic efficiency of remote sensing data applications to natural resources can be expressed both directly (in the reduction of the cost of mapping) and indirectly (by an

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

increase in the quality, reliability, detail, and information of the results). The economic benefits of using remote sensing are very difficult to estimate. The cost of remote sensing data is dependent on the cost for the entire system, consisting of data acquisition, processing and analysis components. This can be broken down into major cost items as follows: satellite development and operation, ground receiving stations and pre-processing facilities, and data processing, analysis and presentation to user community (Nanayakkara, 1990). Satellite remote sensing system produce the data provided by ground systems and airborne surveys in a much more intensive (detailed) and specific nature and is project oriented.

Based on the benefits and application of remote sensing and GIS, the tea sector has adopted this approach for studying the loss made by the gardens due to various reasons. Though the gardens are suffering from various losses the major cause of concern for the gardens is the heavy infestations caused by Red Spider attack and *Helopeltis* (Tea Mosquito Bug). So in this project initiatives have been taken to study the bush health using texture analysis and how the bush health is affecting the yield. Now the question arises as to what is red spider attack and *Helopeltis* attack.

A brief description of the two diseases is given below:

1.5.1. Symptoms of *Helopeltis* and it's affect on the garden:

- Mosquito bugs are found in almost all tea growing areas of Assam.
- Both young and adult mosquito bugs damage tea plants by sucking the sap from tea buds.
- Nymphs caused severe damage than adults.
- The affected part of the plant develops a circular stain that is dark brown or black.
- Buds or shoots becomes curled, dried and black producing no yield.
- Badly damaged buds affect the next flush of shoots.
- Affected buds and shoots become infected with the disease of tea stem leprosy where the stems are covered with dark pimples or with swollen trunk disease.
- Most seriously affected plants developed dark green colour and are stunted.
- Mosquito bugs starts from a small area and then spreads to the entire garden.
- This gives the tea field an appearance of uneven development.
- Mosquito bugs prefer moist conditions and mild temperatures.
- Mosquito bug populations are often higher under heavy shade.



Figure 1: A tea garden patch affected by *Helopeltis*

1.5.2. Symptoms of *Red Spider Mite* attack and it's affect on the gardens:

- Mites are tiny animals like insects.
- Mites sucks the sap from leaves causing leaves to change colour, curl, dry up and even fall off.
- Among different types of mites, *Red Spider* mites are the most serious pest of tea and causes severe damage to the crop during the peak growing period.
- Red Spider mites are found on both sides of the leaves.
- They are concentrated along the central rib of the leaves.
- While feeding they do not move at all.

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

- Groups of spider mites often cover themselves lightly with cobweb of short strands of silk.
- That's why they are called as Spider Mites.
- The spider mites are found underneath the silk, walking slowly on the leaf surface.
- Leaves with heavy mite populations often have many tiny white spots on the surface; they are empty sheds skin of mites.
- It sucks the sap of the tea plant and causes the older leaves to fall off that reduces photosynthesis.
- Under severe infestations the young leaves fall off that reduces the yield of harvested leaves.
- Takes a long time for the tea plants to recover after the severe damage.

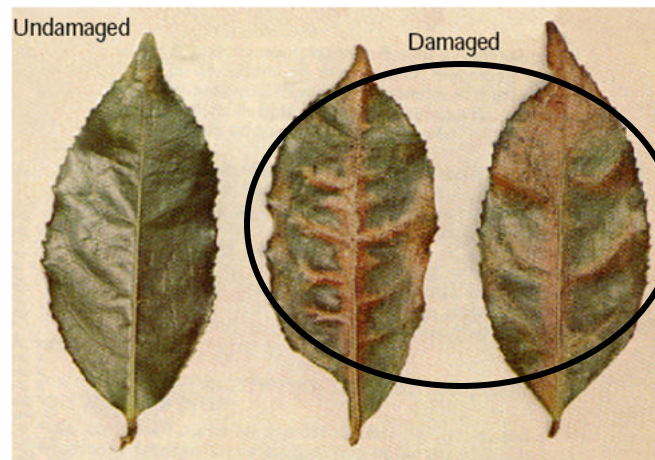


Figure 2: Leaves damaged by Red Spider (TRA Lab)

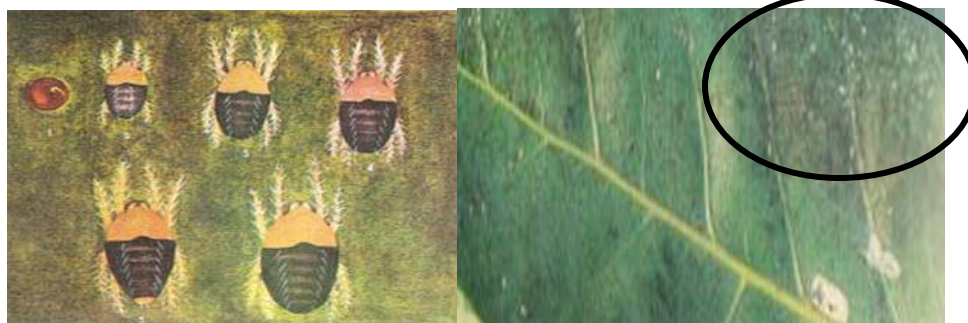


Figure 3: Red Spider Mites

Figure 4: Damaged leaf of a Red Spider Mite



Figure 5: A Garden Patch Showing Both Helopeltis and Red Spider Mite Attack

1.6. Problem Statement

While the tea industry in Assam grew, but with the passage of time it also started facing many problems. The present crisis in the tea industry started in 1999, when unprecedented drought during the early part of the season led to drastic production cuts. Year 2000 saw the marginal improvement in production but there was a sharp drop in price realization. Production in Assam in 2001 was low as compared to the national average. During the year, prices further declined. Export also dropped by 27 million Kgs and Assam could export only 18 million Kgs of tea. It is believed that Assam is losing exports due to wrong production mix, inability to compete with the other tea producing countries due to high cost of production, old age of tea plants, organization of small holder farmers, poor quality control at the processing level and more significantly from pests and disease infestations. From March to November tea plantations suffers from various pest and disease infestations. This is the plucking season and manufacturing of tea takes place during this period. Most severe pest infestation occurs from the tea mosquito bug and thrips. Among the diseases, tea plants are infected by leaf diseases like the **Blister Blight, Red Rot, Black Rot** and **Black Spot**, stem diseases like **Fusarium** and **Dieback** and root diseases like **Charcoal Stump Rot** and **Brown Root Rot**. These disease and pest infestations greatly affect the tea plantations and it's yield during this period. While visiting some of the tea gardens of Sonitpur area it has been found that most of these gardens are suffering from **Red Spider** and **Helopelthis** attack. The quality of Assam tea has also deteriorated in the past couple of years as planters are paying more stress on quantity over quality. Most of the small holder producers faced the problem in tea sector. There is a falling share of producer price and poor infrastructure for the small growers.

1.7. Motivation

Based on the above discussion it is found that research in the field of tea is essential for the upliftment of the gardens as very little work has been done so far in this sector. The lack of previous studies in monitoring tea using remote sensing provided the idea to carry forward the work where some solutions could be given to the garden management for effective decision making in the near future. In this research it has been decided to study the bush health of the tea plantations using the geospatial techniques like the tonal variations and texture analysis and how the bush health is affecting the tea yield. From the texture analysis, the variation in the plantations will be identified and this will be used to interpret whether the area is healthy or moderately healthy or diseased. Once the bush health is identified then its effect on yield will be studied.

1.8. Objectives

- To assess the tea bush health using texture and tonal variations from satellite imagery of tea growing areas and the effect of bush health on yield.
- To examine between yield and derived NDVI

1.9. Research Questions

1. Can tea plants be realistically identified automatically from satellite images like LANDSAT, LISS III and ASTER?
2. What is the role of texture and tone in determining tea bush health?
3. Can we understand the features observed on remote sensing images from field conditions in contexts with the tea planters/farmers?
4. How is tea bush health affecting the production or yield of tea plantations?
5. How can the results obtained be helpful in overcoming the problems of conventional tea practicing methods?
6. Is there any relationship between tea LAI and NDVI using MODIS?
7. Is there any relationship between NDVI and tea leaf yield at critical period?

Based on all the above mentioned factors, this study has been taken to assess the bush health of the tea plantations using the texture analysis and it's affect on the yield.

2. Literature Review

“Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data acquired by a device that is not in contact with object, area or phenomenon under investigation”(Lillesand and Kiefer, 2000). Even in our daily life when we see/hear/read something, we are using the principles of remote sensing. But here we are to deal with only electromagnetic energy sensors that are operated from airborne and space borne platforms to assist in inventorying, mapping and monitoring earth resources. Remote sensing involves two major tasks. These are data acquisition and data analysis. The main elements of data acquisition process are:

- (a) energy sources and its propagation through atmosphere, and
- (b) energy interactions with the earth surfaces and features.

Sensors usually record variations in the way earth surface features reflect or emit electromagnetic energy. Based on how the sensors and electromagnetic energy interact with earth surface features, remote sensing systems are broadly classified in to two categories:

- (a) passive remote sensing system; and
- (b) active remote sensing system (Swain and Davis, 1978).

Passive remote sensing systems record the reflected electromagnetic energy from the features. Here, incident energy is always natural and never from the sensor itself. These sensors use optical part of the electromagnetic spectrum, which extends from approximately 0.3 to 14 μm .

2.1. Optical Remote Sensing for Crop Monitoring:

Assessment of the health of a crop, as well as early detection of crop infestations, is critical in ensuring good agricultural productivity. Stress associated with, for example, moisture deficiencies, insects, fungal and weed infestations, must be detected early enough to provide an opportunity for the farmer to mitigate. This process requires that remote sensing imagery be provided on a frequent basis (at a minimum, weekly) and be delivered to the farmer quickly, usually within 2 days. Remote sensing has a number of attributes that lend themselves to monitoring the health of crops. One advantage of optical (VIR) sensing is that it can see beyond the visible wavelengths into the infrared, where wavelengths are highly sensitive to crop vigour as well as crop stress and crop damage. Remote sensing imagery also gives the required spatial overview of the land. Recent advances in communication and technology allow a farmer to observe images of his fields and make timely decisions about managing the crops. Remote sensing can aid in identifying crops affected by conditions that are too dry or wet, affected by insect, weed or fungal infestations or weather related damage. Images can be obtained throughout the growing season to not only detect problems, but also to monitor the success of the treatment.

2.2. Remote Sensing of Leaf Area Index (LAI)

Leaf Area Index (LAI) defines an important structural property of a plant canopy, the number of equivalent layers of leaves the vegetation displays relative to a unit ground area. FPAR measures the proportion of available radiation in the specific photosynthetically active wavelengths of the spectrum 0.4 - 0.7microns that a canopy absorbs. Because LAI most directly quantifies the plant canopy structure, it is highly related to a variety of canopy processes, such as water interception, evapotranspiration, photosynthesis, respiration, and leaf litter fall. Hence the definition of LAI is used by terrestrial models to quantify the above ecosystem processes. LAI is an abstraction of a canopy structural property, a dimensionless variable that ignores canopy detail such as leaf angle distribution, canopy height or shape. FPAR is a radiation term, so it is more directly related to remotely sensed variables such as simple ratio, NDVI etc. than LAI. FPAR is frequently used to translate direct satellite data such as NDVI into simple estimates of primary production. It does not define plant canopies as directly as LAI, but is more specifically related to the satellite indices. Because the interrelationships between LAI and FPAR are

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

high, and the utility of each is high we plan to produce both. Neither LAI or FPAR are critical variables themselves, rather they are both essential intermediate variables used to calculate terrestrial energy, carbon, water cycling processes and biogeo-chemistry of vegetation. The current consensus is that LAI will be used preferentially by ecological and climate modellers who desire a representation of canopy structure in their models.

2.3. NDVI-LAI Relationship

Several studies have shown that Normalized Difference Vegetation Index (NDVI) and Leaf Area Index (LAI) have been used for yield estimation and prediction. Both these parameters give the vegetation status of the area. It has been observed that NDVI and LAI provide the relation with yield that predicts the yield fluctuations. Many models have been tried in this regards. The LAI is an important vegetation canopy characterization. It is one parameter for crop growth models. The major interest of remote sensing LAI retrievals took place since the launch of earth observation satellite. It is indeed difficult to build accurate and robust retrieval models due to the complexity of relationship between retrieved signal and LAI. But MODIS LAI could be developed and validated (Guissard, 2005). Since NDVI and LAI are obtained from satellite data (Gardner *et.al.*, 1991), the distinction of vegetation and quantitative assessment for growth has become possible. Since plant canopy is composed of leaves, which is a direct source of the energy-matter interactions that are observed by earth-observing remote sensing systems, LAI has been an attractive variable of interest in vegetative remote sensing. However, large portion of such studies to estimate LAI using NDVI were dealing with semi-arid vegetation and agricultural systems where the canopy closure is less than 100%. Studies have also been carried out where the linear models were evaluated using NDVI and field LAI. Cross validation procedure was used to assess the prediction power of the regression models. The study demonstrates that for hyperspectral image data, linear regression models can be applied to quantify LAI with good accuracy (Clement *et.al*, 2004). LAI – NDVI relationship was also used for estimating the evapotranspiration where the relationships between the NDVI – LAI were adjusted by potential model. 57 – 72% variance of NDVI was explained by the LAI (Xavier *et.al*, 2004). Research has also been done where the correlation has been developed between remote sensing data and strawberry growth and yield. Regression analysis was then used to determine the relationship between canopy size and the NDVI from the aerial image. The results showed positive correlation between the two sets of data ($r^2=0.918$). Studies have also been carried out to find the correlation between the maximum latewood density of annual tree rings and NDVI based estimates of forest productivity (Darrigo *et.al.*, 2000). This study showed positive correlations between maximum latewood density data and NDVI based net primary productivity (NPP). Remote sensing from satellite and aerial platforms has been used to detect nutrient status of plants (Blackmer *et al.*, 1996; Wright *et al.*, 2000) and estimate yield (Shanahan *et al.*, 2001; Labus *et al.*, 2002). Some experiments have already been carried out on wheat plants. Most of the yield prediction estimates on larger scales use a simple linear regression model derived from the normalized difference vegetation index (NDVI) with imagery collected during the wheat grain filling period (Benedetti and Rossini, 1993; Doraiswamy and Cook, 1995). Correlation coefficients derived from remote sensing range between 0.7 to 0.83 (r^2) in uniform crop patterns (Raun, et al., 2000) with the expectation of better correlation as spatial and spectral resolution increases and algorithms improve. From the above discussion it is quite clear that correlation and regression between NDVI and LAI could help in linear model development which could further help in estimating and predicting yield.

2.4. Application of Remote Sensing in Tea Sector:

Remote sensing has been in used for quite a long time. Remotely sensed data helps in identifying the vegetation status and allows the users to take appropriate actions at the appropriate time. Lot of research work has also been carried out in the agricultural sector from crop monitoring to damage assessment. But it was observed that very less work has been done in the tea sector. As such few research works have been carried out in the tea sector using remote sensing and GIS.

As tea is a very important beverage, from both management and commercial point of view, an attempt has been made to predict tea yield using remote sensing and GIS and other key parameters in the GIS environment (Tripathy *et.al*).

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

Leaf area index (LAI) is one main key factor useful in crop growth models that may be derived from optical remote sensing data. LAI plays an important role in both the processes of crop growth and canopy reflectance (Clevers *et al.*, 1994). The normalized difference vegetation index (NDVI) is used as a measure of plant productivity (Sellers, 1985). It has also been considered as a measure of LAI for most of crops (Gong, *et al.*, 1995). So NDVI-LAI could be used to study the vegetation status of the crop.

There have been many attempts to estimate LAI using various types of remote sensing data since the early stage of space remote sensing (Badwhar *et al.*, 1986; Peterson *et al.*, 1987; Turner *et al.*, 1999). Remote sensing estimation of LAI has been primarily based on the empirical relationship between the field-measured LAI and sensor observed spectral responses (Curran *et al.*, 1992; Peddle *et al.*, 1999). As a single value to represent the remotely sensed spectral responses of green leaves, spectral vegetation indices, such as normalized difference vegetation index (NDVI) or simple ratio, are frequently used to indirectly estimate LAI. Normalized difference vegetation index (NDVI) has been a popular index with which to estimate LAI across diverse ecosystems. Recent studies have shown that the NDVI may not be very sensitive to values of LAI in particular at the forest ecosystem having the close canopy condition that the LAI value is relatively high (Chen and Cihlar 1996, Turner *et al.* 1999). Since NDVI and are obtained from satellite data (Gardner *et.al.*, 1988 and Baret *et.al.*, 1991) the distinction of vegetation and quantitative assessment for it's growth stage and the estimates of it's carbon absorption and evapotranspiration (Nimani *et.al.*, 1989 and Ebisu, 2000) become possible (Ogawa, *et.al.*, 2000). Using optical and radar satellite data, crop specific LAI could be obtained for growth monitoring and modelling (Guissard *et.al.*, 2005).

It has also been found that spectral characteristics of tea plants are very important for monitoring the tea plantations by remote sensing. A study was carried out in Sri Lanka where LAI of the tea canopy and spectral reflectance of different types of tea clones for different pruning ages were studied in fifty tea fields in the estate and an empirical model between NDVI and LAI of tea canopy was developed (Rajapakse *et. al.*, 2001).

An attempt has also been made to develop a GIS anchored web enabled Decision Support System (DSS) for tea enterprises, introduction of precision farming, user friendly IT framework for collection of spatiotemporal data and efficient and smart Enterprise Resource and Planning (ERP) package for decision support at all levels for better management and profitability (Ghosh *et.al.*, 2004).

Some work has already been carried out in West Bengal, India where remote sensing has been used for finding the ground water availability in the tea growing areas of Terai Region. The study has revealed that satellite remote sensing combined with other conventional data has great potential for ground water exploration (Duarah *et.al.* 1993).

It is observed that water management is an important factor for augmenting the productivity of perennial crops like tea. A study was carried out on the landuse and ground water potential through remote sensing technique in the Darrang and Sonitpur District of Assam (Bordoloi *et.al.*, 1994).

Attempt has also been made to use porphyrin derivative, n-tetraphenyl porphine manganese (111) chloride, thin films for detection of tea aroma using optical fibre reflectance with three different colour LED's i.e., red, yellow and green as the light sources (Akrajas *et.al.*, 2000).

Researches have also been carried out on determining the tea quality by using neural network based electronic nose. Metal oxide sensor based electronic nose (EN) have been used to analyze five tea samples with different qualities in oven. The metal oxide used has electronic resistance with partial sensitivity to headspace of tea. The data were processed using Principal Components Analysis (PCA) and Fuzzy C Means algorithm (FCM). It was found that EN was able to discriminate between the flavours of tea manufactured under different processing conditions (Dutta *et.al.*)

The electronic nose (ER) was also applied for aroma characterization of orthodox black tea where orthodox samples were tested using Alpha MOS 2000 Electronic Nose and data obtained from the experimental setup have been classified using PCA and Black-propagation Multi Layer Perceptron model (Bhattacharyya *et.al.*).

Experiments have also been conducted for the measurement of plural tea information using fibre-optic sensor. Fibre reacts to various signals like temperature and pressure. The plural tea information using the multi-functional technique was measured with optical fibre (Zhu *et.al.* 2004).

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

Attempts have also been made to model the influence of irrigation on potential yield of tea where the CUPPA Tea model was validated against the yield data from irrigation experiments carried out on contrasting soil types at Siliguri and Tezapore regions of North-East India (Panda *et. al.*, 2002).

3. Study Area

3.1. Study Area

3.1.1. Location

Sonitpur district is spread over an area of 5324 sq. Kms. on north bank of Brahmaputra river. In terms of area Sonitpur is the second largest district of Assam after Karbi Anglong district.

Boundaries: **North:** The state of Arunachal Pradesh.

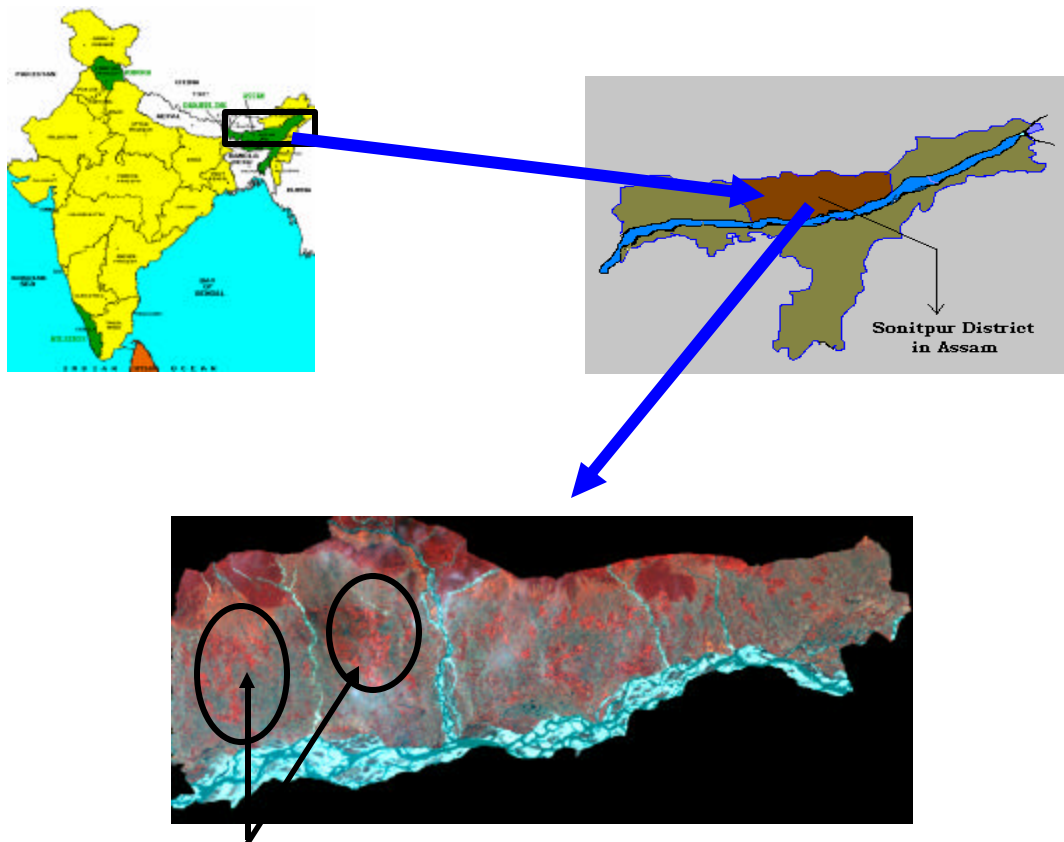
South: Morigaon, Nagaon, Jorhat and Golaghat districts.

East: Lakhimpur District.

West: Darrang District.

(Pachnai river serves as the boundary)

The District lies between 26° 30'N and 27° 01'N latitude and between 92° 16'E and 93° 43'E longitude. Located between mighty Brahmaputra River and Himalayan foothills of Arunachal Pradesh, the district is largely plain with some hills. Brahmaputra River forms the south boundary of the district. A number of rivers which originate in the Himalayan foothills flow southwards and ultimately fall in Brahmaputra River.



Tea Garden Patches

Figure 6: LANDSAT ETM+ showing the tea garden patches

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

3.1.2. Population

According to the 2001 Census, the Sonitpur District has a population of 16,77,874, with a density of 315 persons per sq. km. In terms of population it ranks third in Assam after Kamrup and Nagaon districts. The people here are a heterogeneous lot. Rather, they are a mosaic of ethnic groups, an admixture of diverse types of people.

3.1.3. Climate

Sonitpur District falls in the Sub-Tropical climatic region, and enjoys Monsoon type of climate. Summers are hot and humid, with an average temperature of 29° C. The highest temperature is recorded just prior to the onset of Monsoon (around May-early June). Summer rain is heavy, and is principally caused from late June to early September by the moisture-laden South-West Monsoon, on striking the Himalayan foothills of the north. Such rain is both a boon and a bane for the people. A boon, for it provides natural irrigation to the fields; and a bane, as it causes the rivers to overflow their banks and cause floods. Autumns are dry, and warm. It gets cooler as the months progress. Winters extend from the month of October to February, and are cold and generally dry, with an average temperature of 16° C. It gets quite chilling in late December and early January, on account of snowfall in the upper reaches of Arunachal Pradesh. Springs are cool and pleasant, occurring in the months of late March and April. During these months, flash rains and thunderstorms are at times caused by cyclonic winds, known in local parlance as *Bordoichila*.

3.1.4. Economy

Agriculture is the main occupation of the people of Sonitpur district. Tea gardens are next most important feature of economy of the Sonitpur district. There are all together seventy three tea gardens in Sonitpur district. The area covered under these tea gardens is approximately 2,81,660 Bighas. Monabari near Biswanath Chariali is Asia's largest tea garden. With an area of 1096 hectares with annual tea production of 2632670 Kgs in year 2000. Borgang tea estate is the 2nd largest with 1018 hectors of a total production 1689941 Kgs. Most tea gardens were previously owned by European companies like Mcneal & Magor, George Williamson Ltd., Mcleod Russel, British Assam Tea garden company, Empire Plantation Limited. etc. However in recent years many Indian owned companies like Tata Tea, Brooke Bond etc. have taken over the ownership of the tea gardens. Apart from the big companies recently small tea gardens with area of 40 to 100 bighas have come up in many numbers near the big gardens. They basically sell tea-leaves to the big gardens who own factories.

Major Economic Sector:	Agriculture (70 – 80) %.
Net Area Sown:	1580 sq. km
Production of Winter Paddy:	65780 (Hectares)
Number of Tea Garden:	73
Area under Tea Plantation:	2,81,660 Bighas (Approximately)
Major Fruit Products:	Lichi, Pineapple, Banana
Major Forest Products:	Timber, Stone & Sand.
Major Industry:	Tea Processing, Cane Product, Food Product, Timber Sawing & Tea Machinery Manufacturer.
Village Electrified:	1249 nos.
Total Road Length:	1825.627 Kms.
National Highway:	208.00 Kms (No. 52)

4. Materials And Methods

4.1. Materials

4.1.1. Remote Sensing Data

Data used for this study can be categorized in the following two types: Earth Observation Data and Field Survey Data.

4.1.2. Earth Observation Data:

LISS III Image: The image was taken on 02 February 2004. It has four bands red, green, blue and near infra red. The red, green and near infra red bands are of 23.5 m resolution.

Sensor	LISS III
Resolution	23.5 m
Swath	127 Km (Bands 2, 3, 4) 134 Km (Band 5, MIR)
Repetivity	25 days
Spectral Bands	0.52 - 0.59 microns (B2) 0.62 - 0.68 microns (B3) 0.77 - 0.86 microns(B4) 1.55 - 1.7 microns (B5)

Table 3: Nominal Characteristics of Aster Image

LANDSAT-7 ETM+ Image: The image was taken on December 2001. It includes spectral regions of VNIR (bands 1-4 with 30 m resolution), SWIR (bands 5 and 7 with 30 m resolution and TIR (band 6, with 60 m resolution) and one panchromatic band 8 with 15 m resolutions. The Enhanced Thematic Mapper Plus (ETM+) is the instrument payload on the LANDSAT-7 spacecraft. The ETM+ is a derivative of the Thematic Mapper (TM) instrument on LANDSAT-4 and LANDSAT-5 (Markham, 2003).

Band No.	Band-pass (μm)	Spatial Resolution (m)
1	0.452-0.514	30
2	0.519-0.601	30
3	0.631-0.692	30
4	0.772-0.898	30
5	1.547-1.748	30
6	10.3112.36	120
7	2.065-2.364	30
8 (Pan)	0.515-0.896	15

Table 4: Overview of the nominal characteristics of Landsat-ETM+

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

ASTER Image: The image was taken on June 2004. The Advanced Based Thermal Emission and Reflection Radiometer (ASTER) sensor is an imaging instrument flown on the Terra Satellite which was launched in December 1999. An ASTER scene covers an area of approximately 60 Km x 60 Km and the data is acquired simultaneously at three resolutions. An ASTER scene consists of 14 bands of data with one additional band pointing backwards to create a parallax. The three bands of visible and near infra red part of the spectrum have a 15 m resolution and an 8 bit unsigned integer data type. The six bands in the short wave have a 30 m resolution and also have an 8 bit unsigned integer data type. There are 5 thermal bands with 90 m resolution and have a 16 bit unsigned integer data type.

Band	Label	Wavelength	Resolution
B1	VNIR_Band1	0.52-0.60	15 m
B2	VNIR_Band2	0.63-0.69	15 m
B3	VNIR_Band3	0.76-0.86	15 m(Nadir View)
B4	VNIR_Band3	0.76-0.86	15 m (Backward Scan)
B5	SWIR_Band4	1.60-1.70	30 m
B6	SWIR_Band5	2.145-2.185	30 m
B7	SWIR_Band6	2.185-2.225	30 m
B8	SWIR_Band7	2.235-2.285	30 m
B9	SWIR_Band8	2.295-2.365	30 m
B10	SWIR_Band9	2.36-2.43	30 m
B11	TIR_Band10	8.125-8.475	90 m
B12	TIR_Band11	8.475-8.825	90 m
B13	TIR_Band12	8.925-9.275	90 m
B14	TIR_Band13	10.25-10.95	90 m
B15	TIR_Band14	10.95-11.65	90 m

Table 5: Nominal Characteristics of Aster Image

MODIS/Terra Surface Reflectance 8-Day L3 Global 250m SIN Grid V004 (MOD09Q1)

The surface reflectance product is the input for product generation for several of the land products: Vegetation Indices (VIs), BRDF, Thermal Anomalies, Land cover, Snow/Ice Cover, and LAI/Fpar. It is an estimate of the surface spectral reflectance for each band as it would have been measured at ground level if there were no atmospheric scattering or absorption. This product is a composite using eight consecutive daily 250 m images. The “best” observation during each eight day period, for every cell in the image, is retained. This helps reduce or eliminate clouds from a scene. The file contains the same spectral information as the daily file listed above, centred at 645 nm and 858 nm. There is one additional band of data for quality control. It has three layers and the layer1 and 2 has been used for NDVI computation. The surface reflectance (MOD09Q1) and NDVI derived from surface reflectance image shown was retrieved from MODIS data during April, June and August from 2000 to 2005 over Sonitpur district of Assam, India.

4.1.3. Field Survey Data:

4.1.3.1. Ground Truth Data Collection:

This set of ground truth data will be used for image classification and validation. The homogeneous areas in the field are identified. The GPS is used for taking the coordinates of the area from where the reading is being collected. The field data is collected in the following ways:

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

1. 16 gardens chosen out of 64 gardens in the area based on high yield, medium yield and low yield. (4 gardens = high yield, 4 gardens = medium yield and 4 gardens = low yield).
2. Area was surveyed using GPS.
3. Areas of all the gardens were collected.
4. Leaf Area Index (LAI) collected using a plant canopy analyzer.
5. Management practices for the last 4 years were collected from all the 18 gardens.
6. Last 10 years yield data (1994-2004) of all the 64 gardens were collected from Tea Research Association, Jorhat, Assam.
7. Last 10 years meteorological data on daily and monthly basis were collected from Tea Research Association Sub Station, Rangapara, North Bank, Assam.
8. Soil information like the pH, carbon percent, potash and sulphur contents were collected from all the 18 gardens.
9. Time of irrigation and frequency of irrigation were also collected from all the 18 gardens.
10. All available maps of the gardens were collected.
11. The affected garden patches were identified. Two types of diseases found in the area are red spider mite attack and *Helopeltis*.

4.1.4. Software's Used

(i). ERDAS IMAGINE 8.7 (ii). ENVI 4.1 (iii). SPSS Package

4.1.5. Other Instruments Used

(i) Plant Canopy Analyzer (ii) Hand held GPS (Magellan)

4.2. Data Preparation:

There are distortions and degradations in the raw remote sensing images due to many reasons such as the sensors, the platform and the atmospheric condition when images were taken. Before classification, the raw remote sensing images need some sort of corrections, which is called the image pre-processing. Remote Sensing image pre-processing includes geometric correction, atmospheric corrections and noise removal. In this study the LANDSAT, LISS III and ASTER images have been geometrically corrected. The field survey data includes the knowledge of the study area and the GPS points recording coordinates of homogeneous landcover types of the area.

4.2.1. Georeference of the Data:

The information in the raw remote sensing images has no relation to the real world coordinates. Georeference is a process that establishes the relation between row/column numbers and real world coordinates. Georeference tie points: specifying reference points in an image so that specific row/column numbers obtain a correct X, Y coordinate.

In this study, LISS III, ASTER images were georeferenced using the polyconic projections with Root Mean Square Error (RMS) of 0.345 and 0.325 respectively. MODIS and LANDSAT-7 ETM+ data was reprojected to Polyconic projections as the two data sets obtained were at Sinusoidal and UTM projections respectively. The projection details were given below:

Projection Type: Polyconic

Spheroid Name: WGS 84

Datum Name: WGS 84

Longitude of Central Meridian: 93:03:19.335 E

Latitude of Origin of Projection: 26:46:6.675 N

False Easting at Central Meridian: 2000000 meters

False Northing at Origin: 2000000 meters

4.2.2. Geometric Correction of Remote Sensing Data:

The objective of geometric correction is to compensate for the distortions and degradations caused by the errors due to variation in altitude, velocity of the sensor platform, variations in scan speed and in the sweep of the sensors field of view, earth curvature and relief displacement. The method to do the geometric

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

correction can be divided into two steps according to the different kinds of errors. For the systemic error, geometric correction can be done relatively easily and the errors are corrected for at the receiving station. The random distortion needs to be corrected by the analyst through selecting sufficient number of ground control points with correct coordinates usually from maps or GPS points, which can be accurately localized in satellite images. Then through a transformation function it determines the correct coordinates for the distorted image positions and forms an undisturbed output grid. After this, each cell in this new grid is assigned a grey level according to the corresponding pixel in the original image and the process is called resampling. As the cells in the original image and the new grid are not overlapped, the DN values cannot be assigned by simply overlaying the two but it is done through some interpolation methods. Commonly used resampling algorithms are:

Nearest Neighbour: The pixel value is assigned the DN value of the closest pixel in the original image. This method closely preserves the original image spectral information but because this method will cause one half pixels mismatched, so images resampled by this method are slightly disjointed.

Bilinear Interpolation: Distance weighted average is calculated over the four nearest pixels in the original image and this value is assigned to the new pixel. This method will change the original image information by changing the DN values of the pixels in the image.

Cubic Convolutions: A polynomial approach based on the values of sixteen surrounding pixels is applied and the values calculated by this approach are assigned to new pixels. This method will also change the original image information. The images used in this study are corrected geometrically by using the ground control points (GCP's) from the field and resampled by nearest neighbour.

In this study the resampling algorithm used was nearest neighbour for the geometric correction of the images.

4.2.3. Visual Interpretation of The Images

Remote Sensing is the science and art of obtaining information about an object/phenomena or area through the analysis of data acquired by a device that is not in contact with the object under investigation. The technology involves both satellite and aerial remote sensing. The basic source for this technology is electromagnetic radiation and this energy from the sun reaches the earth surface and again reflected or transmitted or absorbed by the objects which is collected by the satellite sensors. The reflectance/remittance/absorption of energy by an object forms the base for the brightness or darkness in an image or photographs. This is further interpreted for the identification of the features. Once a satellite image is obtained, it is first interpreted to identify the features in the image. The interpretation may be both visual or digital or combination of both. The entire process of visual interpretation can be divided into following few steps namely detection of an object, interpretation, recognition and identification, analysis, classification, deduction and idealisation and based on this identifying an object conclusion. Hence interpretation is the combined result of identification of feature through photo recognition elements, field verification and preparation of final thematic maps. It also requires the process of observation coupled with imagination and great deal of patience.

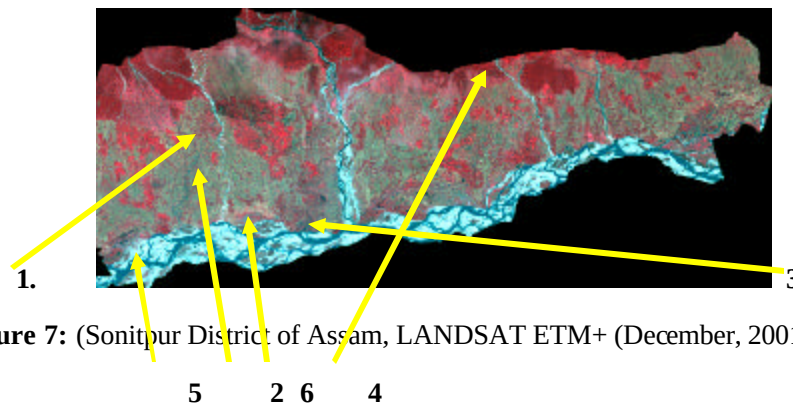


Figure 7: (Sonitpur District of Assam, LANDSAT ETM+ (December, 2001)

1. Tea Patches 2. Barren Land 3. River 4. Forest 5. River Bed 6. Settlements

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

In this study the remote sensing images used are the LISS III, LANDSAT ETM+ and ASTER. All the three images are taken at three different dates to see the variations in the plantation areas. After correcting the images both geometrically and radiometrically the next step that was carried out was masking out the study area. Then the false coloured composite was generated and the interpretation of the images were carried out using the various interpretation keys like the shape, size, pattern, tone, texture, shadows, location, association and resolution. Using the shape man-made features as well as the natural features like the river, hills, river beds were identified from the image. Using pattern, the airstrip, railway tracks as well as the road networks were identified. Though roads and railway tracks looks linear but both can be distinguished from each other as the major roads are associated with steep curves and many intersections with the minor roads. Shadow shows the height of the terrain. Taller features will show larger shadows than the shorter features. Tone shows the brightness of the object based on the reflection, emittance, transmission or absorption character of an object. Using the tonal variations the vegetation status of the area was identified. The tea patches were categorized into healthy, moderately healthy and diseased tea patches based on the smooth and rough surfaces showing the higher and lower reflectance respectively. Similarly scrubs, forest and barren land were identified. Healthy vegetation reflects infrared radiation much stronger than green energy and appears very bright in the image. Using the texture, the tonal change was observed. It gives the smoothness and roughness of the area. Texture directly depends upon the shape, size, pattern and shadow. The texture images were generated for each band on the basis of different texture parameters.

4.2.4. Spectral Signature Analysis of The Optical Data:

Vegetation reflectance is a function of tissue optical properties, canopy biophysical attributes, viewing geometry, illumination conditions and background effects (Asner, 1998; Barret and Curtis, 1992; Goel, 1998; Jacquemoud *et al.*, 1992; Myneni *et al.*, 1989; Ross, 1981). The biophysical attributes of a vegetation crop shows canopy reflectance characteristics due to three dimensional orientations that provides better structure and opportunities for photons to interact with multiple surfaces of different plant parts, this favouring radiometric reception. Various biochemical factors also affect vegetation reflectance. Weeds and pest infestation strongly affect vegetation reflectance depending on the magnitude of interference. Application of multispectral remote sensing to crop condition monitoring has been adopted for various purposes (Cloutis *et al.*, 1996; Franandez *et al.*, 1994; Wallace *et al.*, 1993). In many case spectral responses of crop conditions have been somewhat mixed due to lack of high spectral resolution and to various symptom causing agents occurring at the same time (Carter, 1993; Tingle; Malthus and Madeira, 1993 and Stoll, 1990). Such information is helpful in assessing the growth status of crop vegetation, in discriminating between species and genotypes and in estimating productivity from remotely sensed datasets (Blackburn, 1998; Yoder and Pettigrew-Crosby, 1995).

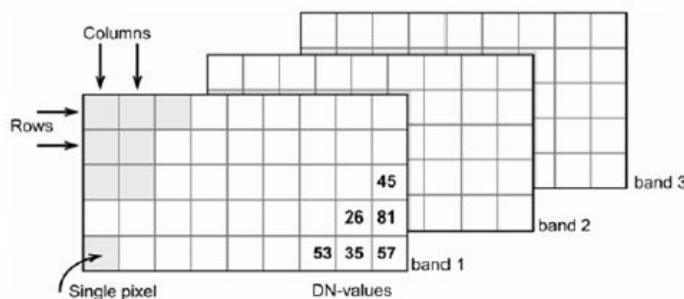


Figure 8: Spectral information in the image (Janssen, 2001)

4.2.4.1. Generation of Spectral Profiles from LANDSAT, LISS III and ASTER Images:

Using the LANDSAT, LISS III and ASTER images, the spectral reflectance profiles were generated. The classes were identified from the images and then the profiles were generated using the standard deviation values. The variations in the bands show the reflectance of different classes present in the

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

images. It was observed from the images that river bed gave the highest reflectance for all the images. In the LANDSAT image, the NIR band showed the high reflectance value for healthy, moderately healthy and diseased tea patches. The LISS III showed high reflectance value in the Band1 (Green) for healthy, moderately healthy and diseased tea patches while Band1 (Green) in ASTER showed high reflectance value for healthy, moderately healthy and diseased tea patches. The profiles have been shown in the results and discussion chapter.

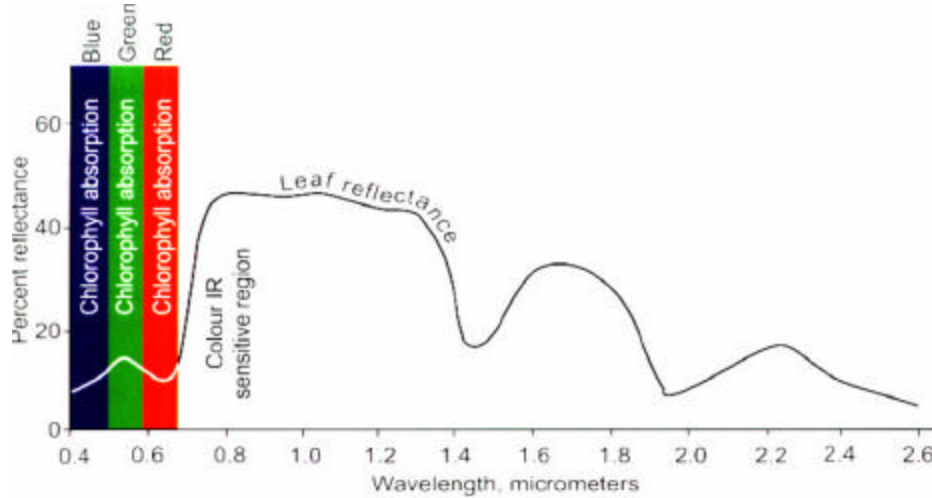


Figure 9: Spectral Reflectance of Healthy Vegetation

Source: Janssen and Huuenemen (2001)

4.2.5. Processing of the Images

The garden boundaries in polygon coverage were generated and overlaid over the images to identify the respective gardens of the area.

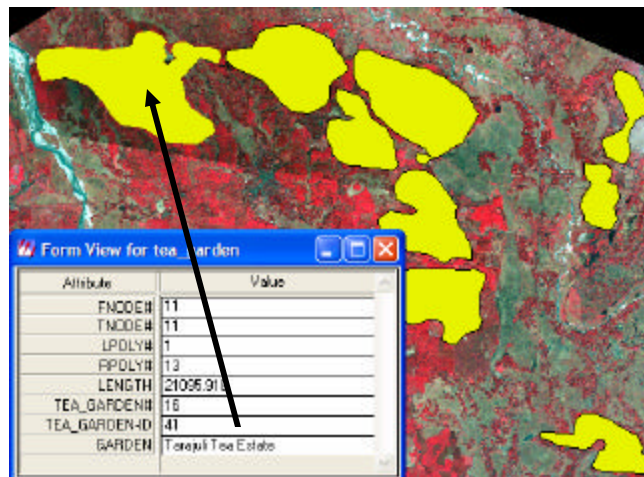


Figure 10: LANDSAT Image Showing the Garden Boundaries

4.2.6. Image Classification

The basic assumption for image classification is a specific part of the feature space corresponding to a specific class. Classes have to be distinguished in an image and classification needs to have different spectral characteristics. This can be analyzed by comparing spectral reflectance curves. Image

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

classification gives results to certain level of reliability. The principle of image classification is that a pixel is assigned to a class based on its feature vector by comparing it to predefined clusters in the feature space. Doing so for all image pixels result in a classified image (Janssen, 2001). There are two approaches for classification. One is the pixel based image analysis approach and the other object oriented image analysis approach. For this study Pixel Based Image analysis approach was used.

A. Unsupervised Classification: The unsupervised classification was carried out for all the three images. The spectral classes obtained from the unsupervised classification are based solely on natural groupings in the image values. The spectral classes obtained from all the three images were not initially known. So taking the reference values, the classified data was compared and the spectral classes were identified.

B. Supervised Classification: Here the image analyst supervises the pixel categorization process by specifying, to the computer algorithm, numerical descriptors of various landcover types present in the image. Training samples that describes the typical spectral pattern of land cover classes are defined. Pixels in the image are compared numerically to the training samples and are labeled to landcover classes that have similar characteristics.

(a). Ground Truth and Crop Classification:

Ground truth data were collected by integrated use of global positioning system (GPS), geocoded FCC (False Colour Composite) of LANDSAT (December, 2001), LISS III (February, 2004) and ASTER (June, 2004). The topographic maps could not be used as the area comes under the purview of the restricted area. Ground truth information corresponding to various landuse/landcover classes were collected after critically examining the spectral variations in the geocoded FCC. The field trips were carried out from 6th August to 16th August, 2005. The complete enumeration process was followed to obtain the information on the landuse/landcover class. ERDAS Imagine 8.7 was extensively used for image processing and interpretation of satellite imageries in this study. All the images were georeferenced to Polyconic projection using the ground control points and resampled to the required pixel size using nearest neighbour method. The images were mosaiced to cover the entire study area. The image correspond to the study area was then clipped out using the district boundary. The samples for different landuse/landcover classes were defined interactively on the three different images of LANDSAT, LISS III and ASTER based on the homogeneity of the samples like the uniform colour of the images and the information collected during field visits.

For crop identification, supervised classification was performed for all the images. All the three classification techniques like the maximum likelihood classification (MLC), parallelepiped and minimum distance to mean classification have been applied for the images and the best classification technique was then found out. It was observed that Maximum Likelihood Classification (MLC) was giving good results as compared to the other two techniques. On the date of acquisition, it was observed that all the tea plants exhibited a range of ground cover, canopy density and affected tea patches. Further using these classified maps the diseased patches were delineated and the shift in the diseases was observed.

C. Accuracy Assessment

In accuracy assessment the main assumption is that the reference data or field data are correct. Classification accuracy will be determined by using three complementary measures which are based on error matrices or confusion matrix derived from independent field data.

The two methods used for accuracy assessment are:

a. The Error Matrix:

Error matrix is a square with the same number of information classes that will be assessed as the row and column. Numbers in rows are the classification result and numbers in columns are reference data. In the error matrix the elements in the diagonal are pixels that are correctly classified. Error matrix is the most effective way to represent map accuracy.

Overall accuracy: It is the proportion of all reference pixels, which are classified correctly. It is computed by dividing the total number of correctly classified pixels by the total number of reference pixels. Overall accuracy can be given by:

$$OA = \frac{\sum_{k=1}^N a_{kk}}{\sum_{i,k=1}^N a_{ik}} = \frac{1}{N} \sum_{k=1}^N a_{kk}$$

Overall accuracy is a coarse measurement. It gives no information about what classes are classified with good accuracy.

- **Producer's accuracy:** It estimates the probability that a pixel which is of class I in the reference classification is correctly classified. It is estimated with the reference pixels of class I divided by pixels where classification and reference classification agree in class I. The equation is given below:

$$PA(Class I) = \frac{a_{ii}}{\sum_{i=1}^N a_{ki}} .$$

Producer's accuracy tells how well the classification agrees with reference classification.

- **User's accuracy:** It is estimated by dividing the number of pixels of the classification result for Class I with the number of pixels that agree with the reference data in class I. It is given by

$$UA(Class I) = \frac{a_{ii}}{\sum_{i=1}^N a_{ki}}$$

User's accuracy predicts the probability that a pixel classified as Class I is actually belonging to Class I.

b. Kappa Statistics

It is a discrete multivariate technique used in accuracy assessment for statistically determining if one error matrix is significantly different than another (Bishop et.al, 1975). The result of performing a

Kappa analysis is a KHAT statistic ($\hat{k}$, an estimate of Kappa) which is another measure of agreement or accuracy. This measure of agreement is based on the difference between the actual agreements in the error matrix and the chance agreement which is indicated by rows and column totals.

(b). Assessing the Accuracy of the Classified Images

In this study, accuracy assessment of MLC based crop/landuse classes was achieved in the form of error matrix by comparing classified output with the ground truth information of independent sites, collected using GPS. A total of 375 sample sites/field was geo-located with GPS for comparison with classified landcover types: healthy tea patches, moderately healthy patches, diseased tea patches, scrubs, river, river bed, barren land and settlements. Overall accuracy was defined as the percentage of total independent reference pixels that were correctly classified by the MLC. Producer's accuracy was calculated by dividing the number of pixels correctly classified for each class by the total number of independent reference pixels for that class while the user's accuracy was the number of correctly classified pixels divided by the total number of classified pixels for that class. The accuracy results are discussed in the results and discussion chapter.

4.2.7. Texture Analysis

Texture analysis has been extensively used to classify the remotely sensed images. Landuse classification where homogeneous regions with different types of terrains need to be identified is an important application. Haralick *et.al* uses gray level co-occurrence features to analyze the remotely sensed images. They computed the gray level co-occurrence matrices for a distance of one with four directions (0° , 45° , 90° and 135°). Identifying the perceive qualities of texture in an image is an important first step towards building mathematical models for texture. The intensity variations in an image which characterize texture are generally due to some physical variations in the scene. Texture is usually characterized by the two dimensional variations in the intensities present in the image. Texture is a property of areas and the texture

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

of a point is undefined. Texture involves the spatial distribution of gray levels. Texture in an image can be perceived at different scales or levels of resolution. A region is perceived to have texture when the number of primitive objects in the region is large. Image texture has a number of perceived qualities which plays an important role in describing texture. Many different approaches to texture analysis have been proposed. Texture does not have a structured definition. It is defined under different definitions. Some of them are given below:

- We may regard texture as what constitutes a macroscopic region. Its structure is simply attributed to the repetitive patterns in which elements or primitives are arranged according to a placement rule.
- A region in an image has a constant texture if a set of local statistics or other local properties of the picture function are constant, slowly varying, or approximately periodic.
- An image texture is described by the number and types of its (tonal) primitives and the spatial organization or layout of its (tonal) primitives.
- Texture is defined for our purposes as an attribute of a field having no components that appear enumerable.
- A fundamental characteristic of texture is that it cannot be analyzed without a frame of reference of tonal primitive being stated or implied. For any smooth grey tone surface, there exists a scale such that when the surface is examined, it has no texture. Then as resolution increases, it takes on a fine texture and then a coarse texture.

Texture analysis in images is an important area of research. The basic aim of any texture analysis is texture recognition and texture based shape analysis. Texture can be carried out at two levels, statistical and structural. A variety of statistical methods like autocorrelation, co-occurrence approach, edge frequency methods, Laws methods, etc. have been proposed for texture analysis. Among the most widely used texture measures are those derived from grey level co-occurrence matrices or difference histograms.

The **Grey Level Co-occurrence Matrix, GLCM** (also called the **Grey Tone Spatial Dependency Matrix**)

The GLCM is a tabulation of how often different combinations of pixel brightness values (grey levels) occur in an image. GLCM texture considers the relation between two pixels at a time, called the **reference** and the **neighbour** pixel. The Grey Level Cooccurrence Matrix (GLCM) has been described in the image processing literature by a number of names including Spatial Grey Level Dependence (SGLD) etc. As the name suggests, the GLCM is constructed from the image by estimating the pair wise statistics of pixel intensity. Each element (i, j) of the matrix represents an estimate of the probability that two pixels with a specified separation have grey levels i and j . The separation is usually specified by a displacement, d and an angle, q which is represented by equation 1.

$$GLCM = f(d, q) = [h_c(i, j | d, q)] \dots \dots \dots (1)$$

where, $f(d, \theta)$ will be a square matrix of side equal to the number of grey levels in the image and is usually not symmetric. Symmetry is often introduced by effectively adding the GLCM to its transpose and dividing every element by 2. This renders $f(d, \theta)$ and $f(d, \theta + 180^\circ)$ identical and makes the GLCM unable to detect 180° rotations.

1. **Mean:** The GLCM Mean is not simply the average of all the original pixel values in the image window. It is expressed in terms of the GLCM. The pixel value is weighted not by its frequency of occurrence by itself (as in a "regular" or familiar mean equation) but by its frequency of its occurrence in combination with a certain neighbour pixel value.

$$(i) \quad m_i = \sum_{j=0}^{N-1} i(P_{i,j}) \quad (ii) \quad m_j = \sum_{i=0}^{N-1} (P_{i,j})$$

The left hand equation calculates the mean based on the reference pixels, μ_i . It is also possible to calculate the mean using the neighbour pixels, μ_j , as in the right hand equation. For the symmetrical GLCM, where each pixel in the window is counted once as a reference and once as a neighbour, the two values are identical.

2. **Variance:** Variance in texture performs the same task as does the common descriptive statistic called variance. It relies on the mean, and the dispersion around the mean, of cell values within the GLCM. However, GLCM variance uses the GLCM, therefore it deals specifically with the

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

combinations of reference and neighbour pixel, so it is not the same as the simple variance of grey levels in the original image. Variance calculated using i or j gives the same result, since the GLCM is symmetrical.

$$(i) \ s_i^2 = \sum_{i,j=0}^{N-1} P_{i,j} (i - m_i)^2 \quad (ii) \ s_j^2 = \sum_{i,j=0}^{N-1} P_{i,j} (j - m_j)^2$$

3. **Contrast:** This will measure the amount of local variation in the image and is the opposite of homogeneity (when high pixel values concentrate along the diagonal).

$$\text{Contrast} = \sum_{i,j=0}^{N-1} P_{i,j} (i - j)^2$$

When i and j are equal, the cell is on the diagonal and $(i-j) = 0$.

These values represent pixels entirely similar to their neighbour, so they are given a weight of 0.

If i and j differ by 1, there is a small similarity, and the weight is 1.

If i and j differ by 2, contrast is increasing and the weight is 4.

The weights continue to increase exponentially as $(i-j)$ increases.

4. **Homogeneity:** Dissimilarity and Contrast result in larger numbers for more contrasty windows. If weights decrease away from the diagonal, the result will be larger for windows with little contrast. Homogeneity weights values by the inverse of the Contrast weight, with weights decreasing exponentially away from the diagonal

$$\text{Homogeneity} = \sum_{i,j=0}^{N-1} \frac{P_{i,j}}{1 + (i - j)^2}$$

5. **Dissimilarity:** Instead of weights increasing exponentially (0, 1, 4, 9, etc.) as we move away from the diagonal, the dissimilarity weights increase linearly (0, 1, 2, 3 etc.).

$$\text{Dissimilarity} = \sum_{i,j=0}^{N-1} P_{i,j} |i - j|$$

6. **Entropy:** This measure is high when the values of the local window have similar values. It is low when the values are close to either 0 or 1 (i.e. when the pixels in the local window are uniform). Entropy is the degree of diversity. It is given by:

$$E = \sum P_i (\log P_i)$$

Where, P_i is the number of times the element has occurred to the total number of elements.

7. **Angular Second Moment:** It will be used to measure homogeneity of the image. This information is specified by the matrix of relative frequencies $h_c(i,j)$ with which two neighbouring pixels occur on the image, one with grey value i and the other with grey value j.

$$ASM = \sum_i \sum_j h_c(i, j) \text{ for a particular direction.}$$

$$f = \sum_{i=1}^{NG} \sum_{j=1}^{NG} \left(\frac{P(i, j)}{R} \right)^2$$

8. **Correlation:** This will analyze the linear dependency of grey levels of neighbouring pixels. It is typically high, when the scale of local texture is larger than the distance.

$$\text{Correlation} = \sum_i \sum_j (i - m)(j - m) h_c^2 \frac{(i, j)}{d^2}$$

where

$$m = \text{mean} = \sum_i \sum_j h_c(i, j)$$

4.2.7.1. Generating the Texture Images Using Gray Level Co-occurrence Matrix (GLCM)

In this study, an attempt has been made where the Grey Level Co-occurrence Matrix (GLCM) method is used for studying the texture of the tea areas that will enable us to distinguish between the healthy as well as the affected tea patches. The GLCM technique was applied to all the images and the different

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

parameters were studied giving different thresholdings. Once the images were generated then it is compared with the diseased maps to see whether the affects observed on the diseased maps could also be observed on the texture images. It was found that the parameter mean was giving good results as compared to other parameters. The details have been discussed in the results and discussions chapter.

4.2.8. Normalized Difference Vegetation Index

The dominant method for vegetation change detection using remotely sensed data is through vegetation indexes (Deering & Haas, 1980). Vegetation indexes are algorithms aimed at simplifying data from multiple reflectance bands to a single value correlating to physical vegetation parameters (such as biomass, productivity, leaf area index, or percent vegetation ground cover) (Tucker, 1979). These vegetation indexes are based on the well-documented unique spectral characteristics of healthy green vegetation over the visible to infrared wavelengths. Healthy green vegetation generally reflects very little solar energy in the visible wavelengths (0.4-0.7 μm), with a sharp increase in reflectance in the near-infrared wavelength region (0.7-1.1 μm). This “red edge” is unique to vegetation as a surface material. Dead or senescent vegetation and soil generally reflect relatively greater amounts of energy in the visible wavelengths and less in the near- infrared. This unique spectral property of green vegetation is used in various indexes ranging in complexity from applying correlation coefficients to brightness values of a near-infrared band, to multi-band ratioing combined with complex algorithms (Jensen, 1996). Arguably the most successful and commonly used of these techniques is the Normalized Difference Vegetation Index (NDVI). NDVI is the traditional vegetation index used by researchers for extracting vegetation abundance from remotely sensed data (Tucker, 1979). It divides the difference between reflectance values in the visible red and near-infrared wavelengths by the overall reflectance in those wavelengths to give an estimate of green vegetation abundance (Tucker, 1979). In essence, the algorithm isolates the dramatic increase in reflectance over the visible red to near infrared wavelengths, and normalizes it by dividing by the overall brightness of each pixel in those wavelengths. Specifically NDVI is:

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

where the values in either band have been converted from raw DN values to reflectance of solar electromagnetic radiation. The result of this algorithm is a single band data set, ranging from -1 to 1, with values corresponding to photosynthetic vegetation abundance. NDVI has been used extensively to measure vegetation cover characteristics on a broad-scale worldwide, and has been incorporated into many large-scale forest and crop assessment studies (Peterson *et al.*, 1987; Asrar *et al.*, 1984; Bausch, 1993; Benedetti & Rossini, 1993; Hatfield *et al.*, 1985; Wanjura & Hatfield, 1987). It is used to provide weekly vegetation maps, monitor crops over large regions, monitor vegetation change in much of the tropics, and estimate biomass. The limitations of vegetation indexes emanate from the fact that relationships between vegetation abundance and electromagnetic reflectance values in complex forest structures (and areas with high vegetation abundance) are many times nonlinear, whereas vegetation indexes are simple linear algorithms. Therefore, because of increased mutual shadowing in mature stands, aging forests may show a decrease in NDVI while actual biomass increases. Consequently, once vegetation indexes reach a threshold level they no longer accurately correlate to actual vegetation abundance (Begue, 1993; Chance, 1981; Waller *et al.*, 1981; Wanjura & Hatfield, 1987; Wiegand *et al.*, 1991).

4.2.8.1. NDVI Extraction

The NDVI is extracted from the LISS III, LANDSAT ETM+, ASTER and the MODIS images at different dates. Further the tea garden NDVI has been masked out. MODIS NDVI along with the Landuse/Landcover map has been used for 1 x 1 and 3 x 3 pixel extraction. Further analysis was then carried out.

4.2.9. Leaf Area Index (LAI)

Leaf Area Index (LAI) is defined as the one sided green leaf area per unit ground area in broadleaf canopies, or as the projected needle leaf area per unit ground area in needle canopies. The interaction between vegetation surface and the atmosphere, e.g. radiation uptake, precipitation interception, energy

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

conversion, momentum and gas exchange, is substantially determined by the vegetation surface (Monteith and Unsworth, 1990).

Various destructive and non-destructive methodologies to measure or derive LAI do exist. Non-destructive methods include hemispherical photography, sun fleck ceptometers, and other optical instruments like TRAC, LAI-2000 or LI-COR (detailed description of techniques are presented by Chen *et al.*, 1997). In this study the non-destructive method was used. A plant canopy analyser was used in this regard. It has to be taken into account that all methods do have advantages as well as disadvantages in estimating LAI and data are not always directly comparable.

Leaf area index (LAI) is one of the major parameter for determining the crop growth that may be derived from optical remote sensing. LAI during the plucking stage is one of the most important factors. LAI helps in determining the crop reflectance. Relationship between LAI and NDVI is an important factor for predicting the yield. It can be considered as a measure of plant productivity (Sellers, 1985). The Normalized Difference Vegetation Index (NDVI) can be considered as a measure of LAI for most of the crops (Gong *et al.*, 1995). So this relationship can be used for determining the productivity of the tea plantation. Estate latitude, longitude, the acreage, the varieties grown, slope, elevation of the estate, the average annual rainfall of the area, temperature, daily sunshine hour and the relative humidity are the parameters important to carry out the study. The Daily temperature should range from 21 to 23⁰ C. Both attribute and spatial data along with estate record, meteorological data and the measured LAI were used for the analysis. Spatial data may be verified from field samples collected for measuring the LAI. Sample size may vary depending on the requirement. Leaf area was determined by using plant canopy analyzer. The plant canopy analyzer gives the LAI values directly using the equation given below:

$$LAI = \frac{\text{Leaf Area}}{\text{Sample Area}} \dots\dots\dots (1)$$

The tea plant canopy coverage has to be considered from the satellite imagery. Both leaf area and the sample area should have the units.

$$LAI = \frac{\text{Leaf Area}}{\text{Sample Surface Area}} \dots\dots\dots (2)$$

where,

$$\text{Actual Coverge} = \frac{\text{Actual Plant Density}}{\text{Optimum Plant Density}} \dots\dots\dots (3)$$

The Leaf Area Index (LAI) values were collected using the Plant Canopy Analyzer from the tea fields and the GPS point at that particular point was recorded. Three LAI observations were taken from each division of the gardens. The average LAI values for each division were calculated. These LAI values and the GPS points of the gardens were then overlaid over the different images. Using the MODIS LAI values and the field LAI values the LAI variability has been studied. Details of this have been discussed in the results and discussion chapter.

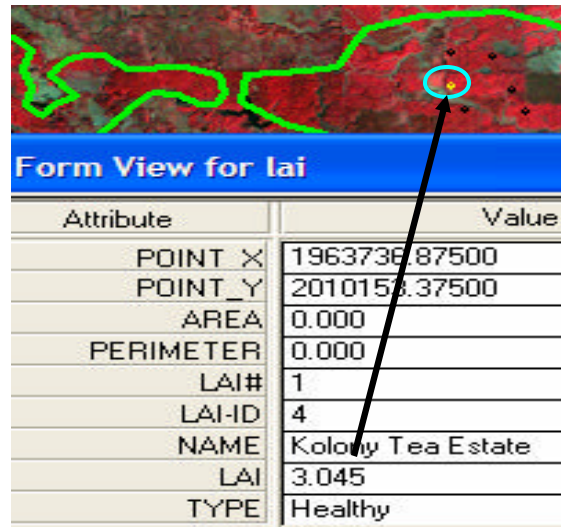


Figure 11: LANDSAT Image Showing the LAI of a Healthy Patch

4.2.10. NDVI-LAI Relationship

MODIS NDVI image was generated and the tea garden patches were masked out. Using the masked NDVI image, the NDVI values were extracted from the tea masked area using 3 x 3 pixel extraction method. The average of the actual LAI and NDVI values were found out and the linear regression analysis was carried out using the LAI and NDVI values. The LAI – NDVI values were plotted in the scatter plot and linearly regressed. From the analysis it was observed that there exist a linear relationship between LAI and MODIS based NDVI.

4.2.11. Statistical Analysis

Correlation and regression were used for estimating the yield.

Correlation: It is the measure of strength of relationship between two variables. It is used to predict the value of one variable given the value of the other. Correlation is computed into what is known as the correlation coefficient, which ranges between -1 and +1. In probability theory and statistics, correlation, also called correlation coefficient, is a numeric measure of the strength of linear relationship between two random variables. The best known is the Pearson product-moment correlation coefficient, which is found by dividing the covariance of the two variables by the product of their standard deviations.

$$\rho_{xy} = \frac{\text{cov}(X, Y)}{\sigma_X \sigma_Y} = \frac{E((X - \mu_X)(Y - \mu_Y))}{\sigma_X \sigma_Y}$$

Since $\mu_X = E(X)$, $s_X^2 = E(X^2) - E^2(X)$ and likewise for Y, we may also write:

$$\rho_{xy} = \frac{E(XY) - E(X)E(Y)}{\sqrt{E(X^2) - E^2(X)} \sqrt{E(Y^2) - E^2(Y)}}$$

If we have a series of n measurements of X and Y written as x_i and y_i where $i = 1, 2, \dots, n$, then the Pearson product-moment correlation coefficient can be used to estimate the correlation of X and Y . The Pearson coefficient is also known as the "sample correlation coefficient". It is especially important if X and Y are both normally distributed. The Pearson correlation coefficient is then the best estimate of the correlation of X and Y . The Pearson correlation coefficient is written:

$$r_{xy} = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{(n - 1)s_x s_y}$$

where $\bar{x}$ and $\bar{y}$ are the sample means of x_i and y_i , s_x and s_y are the sample standard deviations of x_i and y_i and the sum is from $i = 1$ to n . As with the population correlation, we may rewrite this as

$$r_{xy} = \frac{n \sum x_i y_i - \sum x_i \sum y_i}{\sqrt{n \sum x_i^2 - (\sum x_i)^2} \sqrt{n \sum y_i^2 - (\sum y_i)^2}}.$$

Regression

Linear regression is used to explain and/or predict. The general form is:

$$Y = a + bX + u$$

Where Y is the variable that we are trying to predict, X is the variable that we are using to predict Y, a is the intercept, b is the slope, and u is the regression residual.

In this study relationship between NDVI – LAI and the NDVI, ground LAI and MODIS LAI variability were developed to observe the variability and which in turn will help in yield prediction. A year wise correlation was developed between tea leaf yields and MODIS based NDVI of the tea estate during different months. Further tea leaf yield models were also developed to see the variability in the yield using the MODIS NDVI. The details were discussed in the results and discussion chapter.

Methodology:

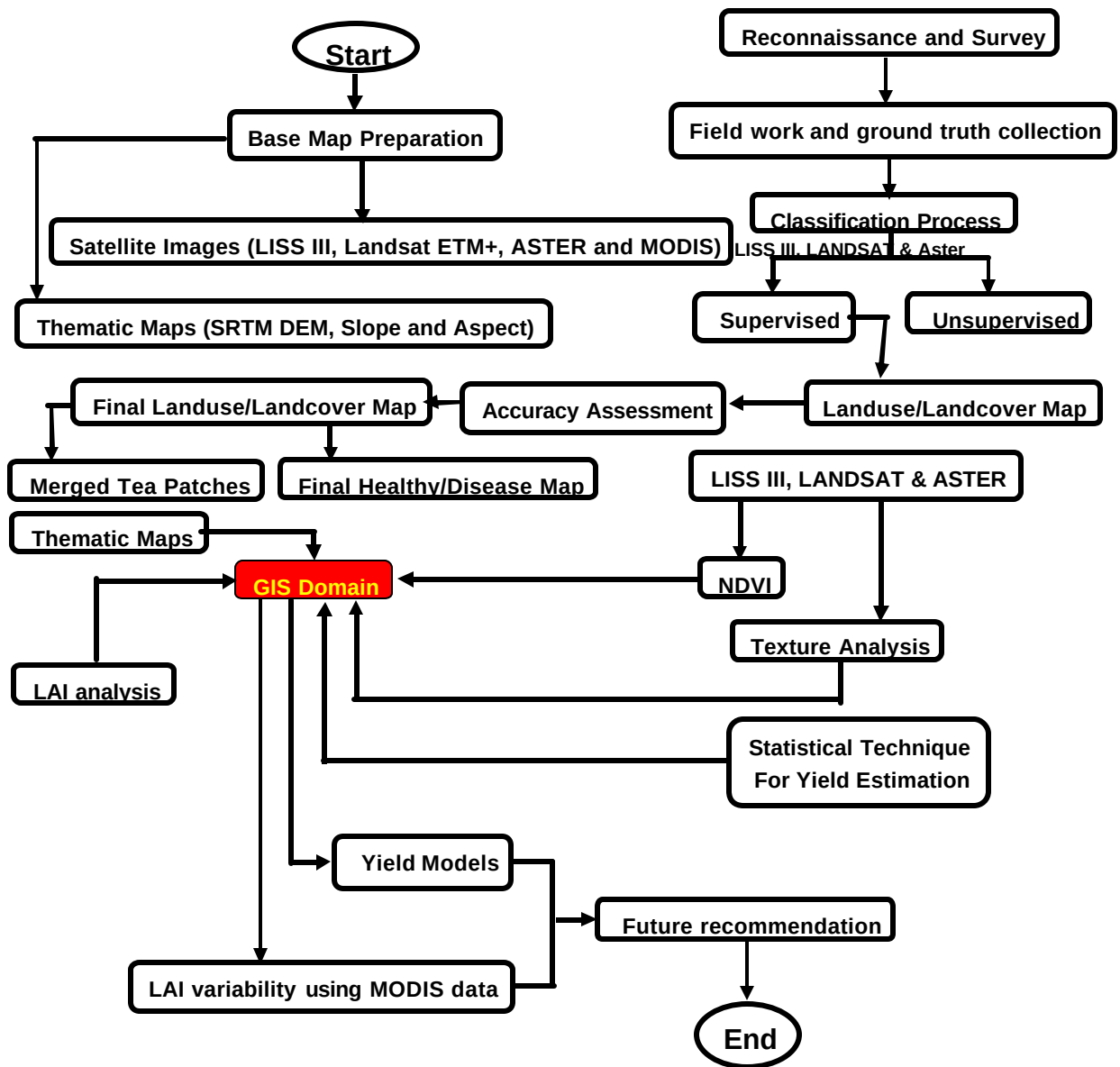


Figure 12: Methodology

5. Results and Discussions

5.1. Visual Interpretation of The Images

In order to detect the affected and non-affected tea patches the temporal images were visually interpreted. The false colour composite (FCC) for LANDSAT, LISS III and ASTER were generated at 4:3:2, 3:2:1 and 3:2:1 respectively. From the FCC the affected and non-affected tea patches could be distinctly separated from the other landuse/landcover classes. From the images (as shown in **figure 13**) it is quite clear that the healthy patches showed bright red appearance, moderately affected patches had reddish brown appearance while the diseased patches showed dark brown appearance.

The landcover classes were described visually as:

1. **Tea Patches:** From the image the tea patches appears to be bright red in colour with smooth texture. The healthy tea patches showed bright red colour due to higher reflectance while the moderately affected patch showed reddish brown in colour. The diseased tea patch showed dark brown colour.
2. **Other Vegetation:** Other vegetation like scrubs gives pink to dark red in colour with both smooth and coarse texture.
3. The **river** gives dark blue reflectance with smooth texture that can be easily separated from the other classes.
4. **River Bed:** The river bed also gives whitish appearance that could be easily distinguished from all the other landcover classes.
5. **Barren Land:** Barren Land gives wheatish green appearance with smooth texture that could be well separated from the other vegetation types.
6. **Settlements:** Settlements shows blackish green reflectance with coarse texture.

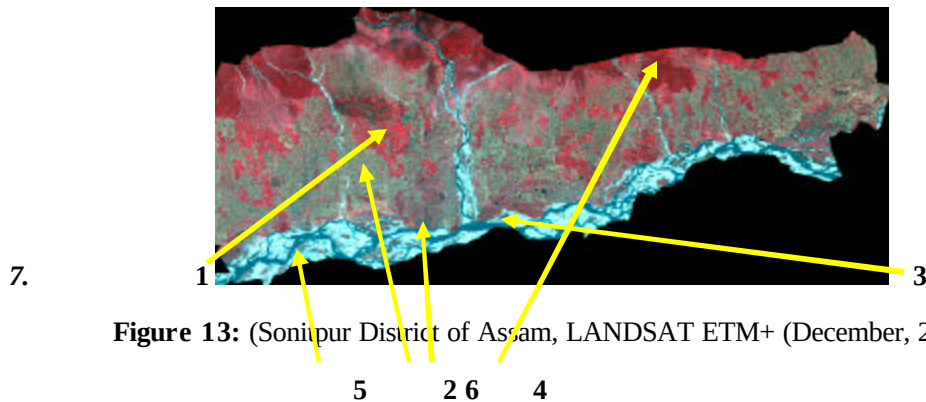


Figure 13: (Sonipur District of Assam, LANDSAT ETM+ (December, 2001))

1. Tea Patches 2. Barren Land 3. River 4. Forest 5. River Bed 6. Settlements

5.2. Results of Spectral Signature Analysis of the Optical Data (LANDSAT, LISS III and ASTER)

The primary objective of spectral signature analysis was to check the separability or to evaluate the spectral separation between landcover classes. The reflectance curves for all bands were generated to study the spectral response pattern of each landcover classes. Line graphs were generated to show the spectral separability of different landcover classes. In an optical image, vegetation can be easily distinguished from its unique spectral signature. The reflectance of the tea patches and other vegetation classes showed high peak in the NIR band. The low peaks shown at the Red region of the spectrum are

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

mainly due to the absorption of chlorophyll. Very importantly it was found that river bed is showing its peak in the Red, NIR and Green region of the spectrum. This may be due to higher reflectance and lower absorption.

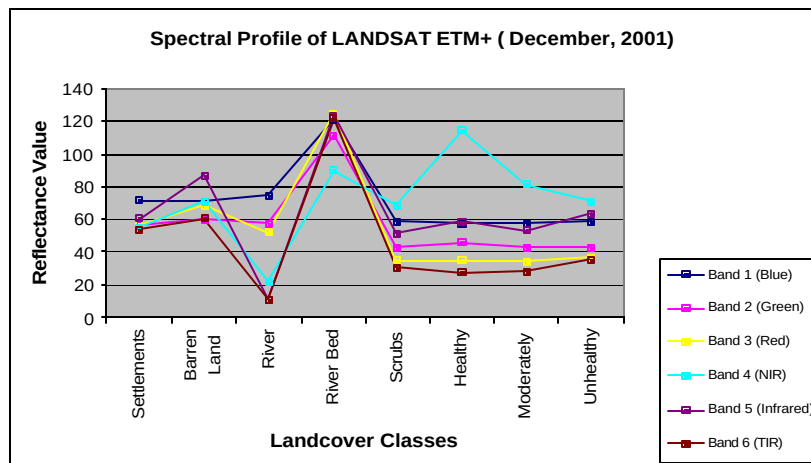


Figure 14: Graph Showing The Landcover Class Seperability in LANDSAT ETM+

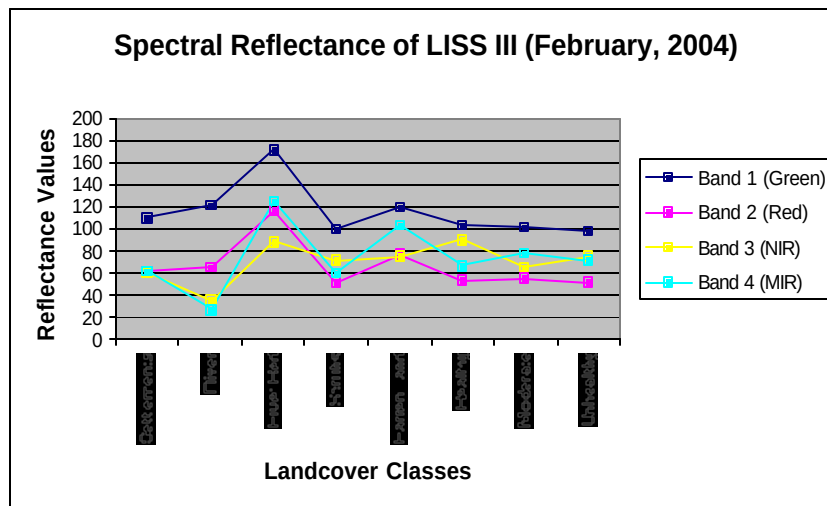


Figure 15: Graph Showing The Landcover Class Seperability in LISS III

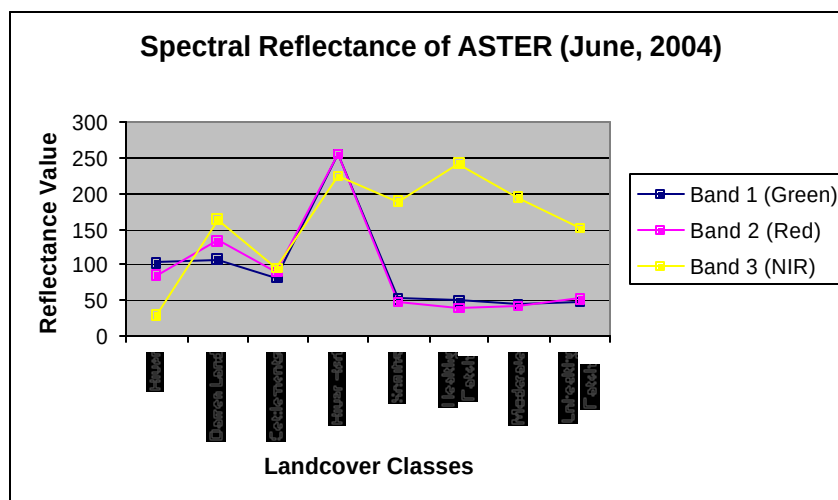


Figure 16: Graph Showing The Landcover Class Seperability in ASTER

The three spectral curves, showed that ASTER has highest peak for healthy, moderately affected and diseased patches in the (NIR) region. Lowest reflectance was obtained from the LISS III image.

5.3. Digital Image Analysis

Images of LANDSAT ETM+ (December, 2001), LISS III (February, 2004) and ASTER (June, 2004) were classified individually with separate training set. Qualitative and quantitative evaluation of the classification results of three different imageries will be presented and discussed below.

Supervised classification was performed using Maximum Likelihood Classifier, Minimum Distance to Mean and Parallelepiped classifier for LANDSAT (of spatial resolution of 30m), LISS III (23.5m) and ASTER images (15m) to classify the image into eight landuse classes namely healthy tea, moderately affected tea, affected tea, river, riverbed, settlements, scrubs and barren land. Vegetation classes like scrubs, settlements, etc. were found to be mixing with tea class. The classes were then validated from the field visits. Maximum Likelihood Classification (MLC) gave the best results as compared to Minimum Distance to Mean (MDM) and Parallelepiped Classification.

5.3.1. Results of Supervised Classification of LANDSAT Image

Supervised classification categorized the image into landuse eight classes (healthy tea, moderately affected tea, affected tea, river, riverbed, settlements, scrubs and barren land) as shown in **Figure. 17**. More classes of vegetation types were avoided to minimize misclassification and confusion among the classes. The classified images were validated with the ground truth data. Maximum Likelihood Classification (MLC) gave the best results as compared to Minimum Distance to Mean (MDM) and Parallelepiped Classification. The overall accuracy of the classified image in MLC was 87.42%.

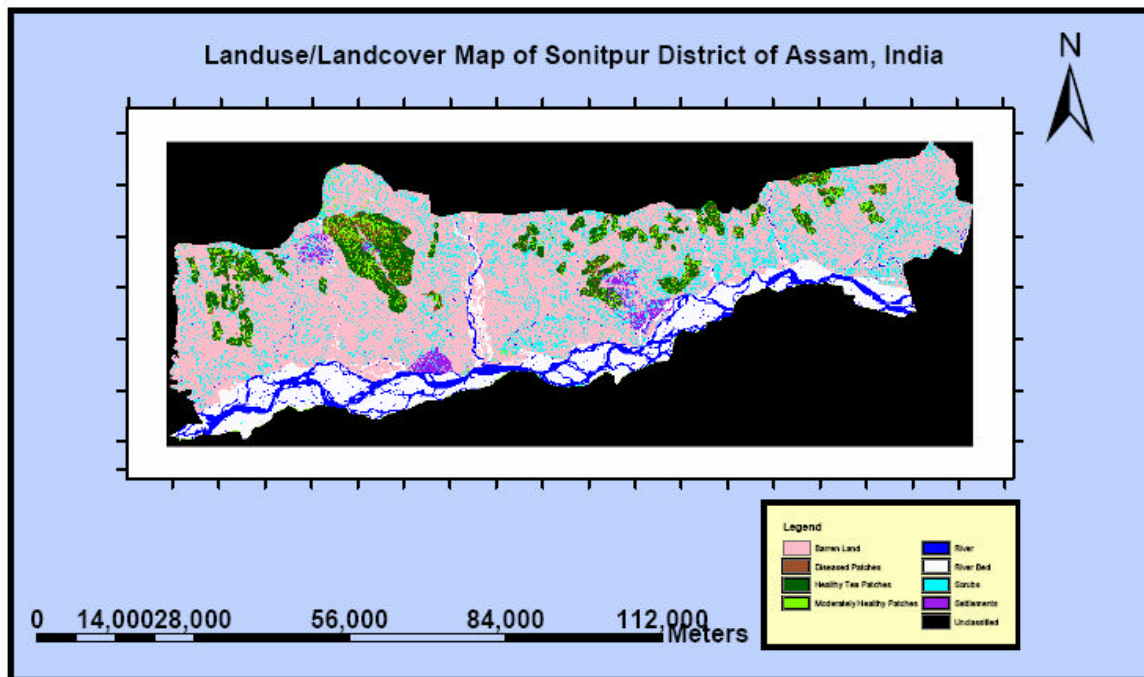


Figure 17: Landuse/Landcover Map of Sonitpur District (LANDSAT ETM+, December 2001)

5.3.2. Results of Supervised Classification of LISS III Image

The LISS III image was classified into same eight classes as mentioned above (healthy tea patches, moderately affected patches, diseased tea patches, barren land, river, river bed, scrubs and settlements). The inclusion of more classes of different vegetation types leads to confusion with other classes and misclassification with classes mixing with each other. Of the three classification techniques MLC showed the lowest degree of mixing. The classified image was validated with the ground truth data. The best result was obtained from maximum likelihood classifier (MLC). The overall accuracy for the LISS III classified image was found to be 86.13%.

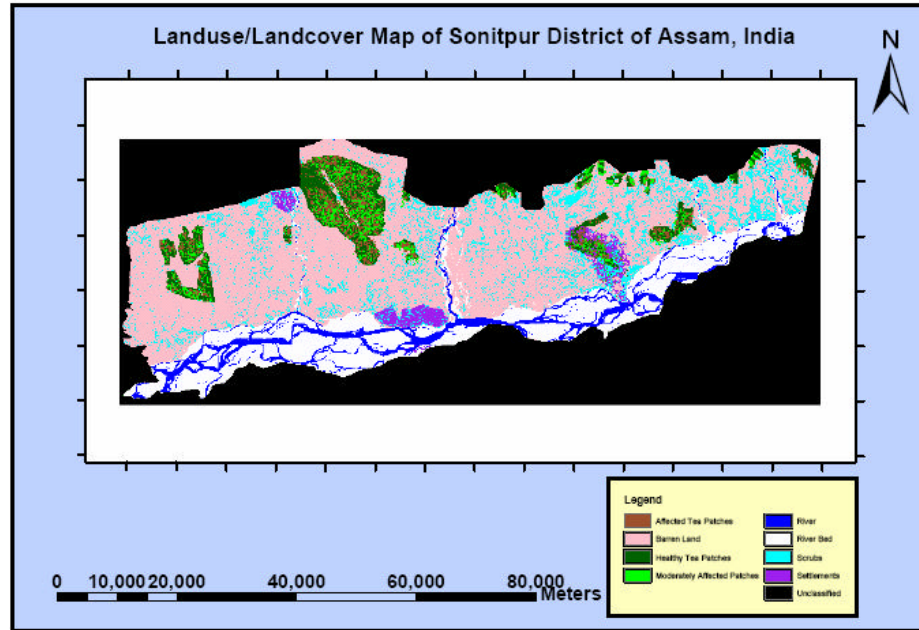


Figure 18: Landuse/Landcover Map of Sonitpur District (LISS III, February 2004)

5.3.3. Results of Supervised Classification of ASTER Image

On the FCC generated, ASTER bands, the tea patches are more prominent than on the LANDSAT and LISS III images. The image was classified using MLC. Minimum Distance to Mean and Parallelepiped classification algorithm into healthy tea patches, moderately healthy tea patches, affected tea patches, settlements, river, river bed, scrubs and barren land. Mixing of classes was comparatively less, in Maximum Likelihood Classifier (MLC) thereby giving the best result. Overall classification accuracy obtained was 87.39%.

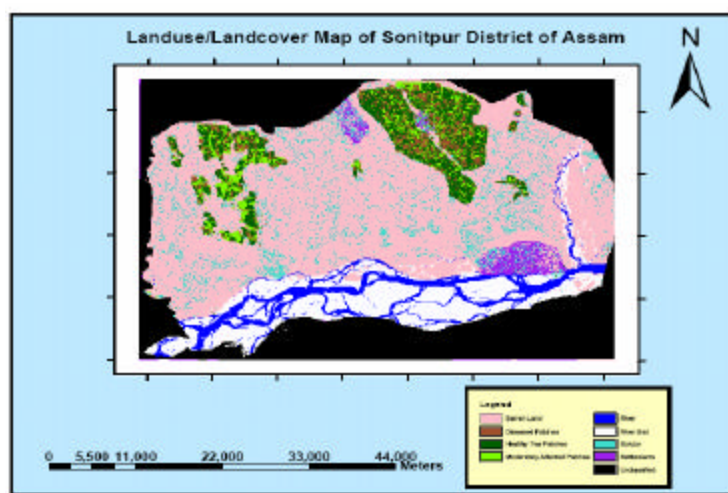


Figure 19: Landuse/Landcover Map of Sonitpur District (ASTER, June 2004)

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

From all the three classification techniques it was found that ASTER image with 15m resolution gives good classification results as there is less mixing and less misclassification.

5.3.4. Quantitative Evaluation of Supervised Classification of the Images

Accuracy assessment determines the quality of the information derived from the remotely sensed data. Through quantitative accuracy assessment we can identify and measure map errors. Accuracy assessment was done for the LANDSAT, LISS III and ASTER classified images. Quantitative accuracy assessment involves the comparison of a site on the map against reference information for the same site. Accuracy requires:

- (i). Design of unbiased and consistent sampling procedures.
- (ii). Rigorous analysis of the sample.

The producer's accuracy denotes how well a particular class can be classified in an image. Users accuracy denotes that the pixels present in a particular class actually belongs to an another class.

Accuracy Assessment is carried out for all the three data sets.

The **Table 6.** and **7** shows producers, users and overall accuracy.

Class Name	LANDSAT ETM+		LISS III		ASTER	
	Producers Accuracy	Users Accuracy	Producers Accuracy	Users Accuracy	Producers Accuracy	Users Accuracy
Healthy Tea Patches	92.86%	93.91%	92.39%	93.3%	93.27%	94.13%
Moderately Healthy Tea	95.35%	95.33%	94.75%	94.55%	95.31%	95.34%
Diseased Tea Patches	91.60%	93.65%	92.07%	93.52%	91.19%	93.29%
Scrubs	50.62%	53.99%	51.75%	57.47%	47.29%	50.66%
Settlements	21.97%	17.08%	17.86%	14.98%	20.00%	15.52%
River	81.17%	83.18%	81.71%	83.55%	81.15%	83.30%
River Bed	61.34%	61.15%	60.23%	58.67%	59.17%	60.64%
Barren Land	65.69%	56.40%	56.56%	46.85%	63.11%	53.30%

Table 6: Accuracy Assessment

Images	Overall Classification Accuracy
LANDSAT ETM+	87.42%
LISS III	86.13%
ASTER	87.39%

Table 7: Table showing the Accuracy Results of the LANDSAT, LISS III and ASTER Images

5.4. Delineation of Diseased Tea Patches

Once the landuse/landcover maps were generated, the garden patches were merged and the other classes were assigned zero value.

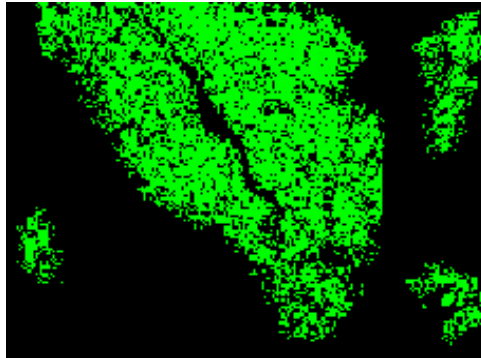


Figure 20: Map Showing Merged Gardens (ASTER, June 2004)

Further the tea garden patches were masked out from the landuse/landcover maps and the disease patches were delineated. From the disease patches one could clearly see the shift in the diseases at three different dates.

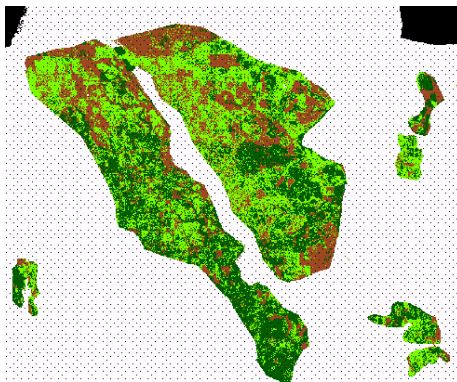


Figure 21: Diseased Tea Patches
(LANDSAT ETM+, December, 2001)

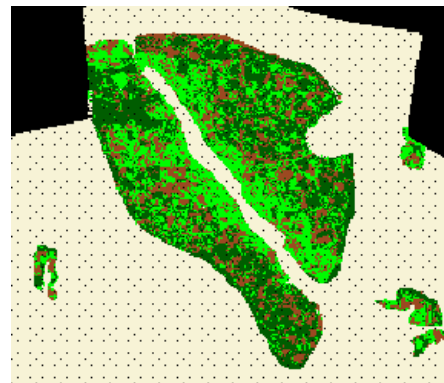


Figure 22: Diseased Tea Patches
(LISS III, Feb. 2004)

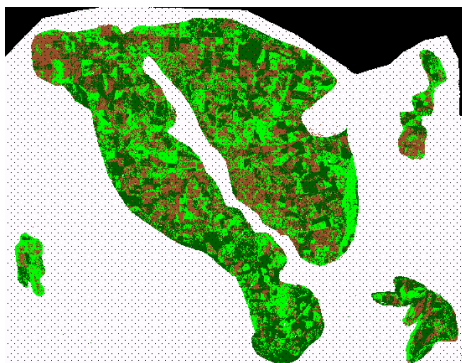


Figure 23: Diseased Tea Patches
(ASTER, June 2004)

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

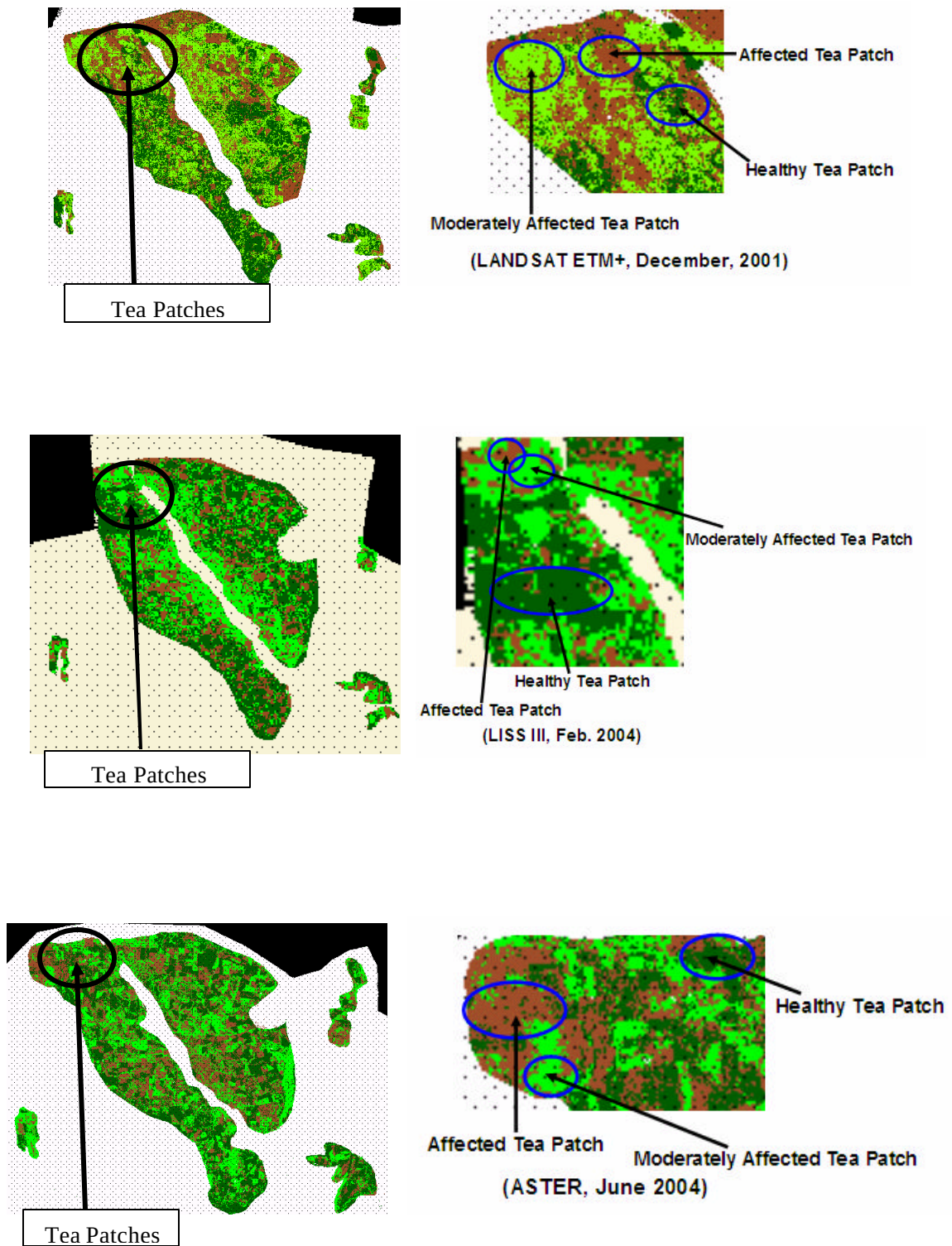


Figure 24: Shift in The Diseases As Seen The Temporal Images

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

There is a gradual shift of the diseased area between 2001 and 2004. In LANDSAT image where the healthy, moderately affected and affected patches were shown the same could not be observed in the LISS III and ASTER image. When compared between LANDSAT and LISS III, it was found that the affected patches of LANDSAT have become moderately affected in LISS III, moderately affected patches have become the affected patches and the diseased patches in have become healthy patches in LISS III clearly highlighting the shift.

Similarly when the ASTER image was compared with LISS III it was observed that the moderately affected patches in LISS III have become healthy patches in ASTER and healthy patches have become diseased patches in ASTER. This gives us an idea how the disease has spread between February and June during the year 2004. Moreover the infestation was found to be more during June 2004 as there were heavy rain accompanied by high temperature and high relative humidity.

5.5. Identification of Diseased Tea Patches Using Texture Analysis

The Grey Level Co-occurrence Matrix (GLCM) method was used for studying the texture of the tea areas that enabled the distinction between the healthy as well as the affected tea patches. The texture analysis has been carried out using ENVI 4.1 software.

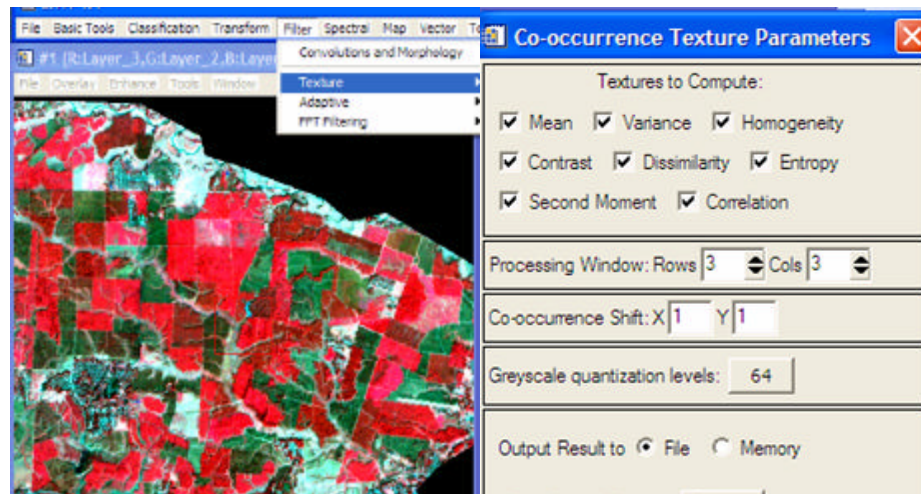


Figure 25: Step I of Texture Analysis

Figure 26: Step II of Texture Analysis

Texture analysis for LANDSAT, LISS III and ASTER images were carried out using various windows like 3 x 3, 5 x 5, 7 x 7, 9 x 9, 11 x 11, 13 x 13, 15 x 15, 17 x 17 and 19 x 19 and the texture images were generated band wise. It was found that only 3 x 3 window gave good results with proper clarity. The other windows gave hazy and blurred texture images from which the tea patches could not be identified and at the same time thresholding of the images was a major problem. The band giving the best texture result in 3 x 3 window was then selected for analysis purposes.

5.5.1. Results of Texture Analysis

For LANDSAT image, Band 4 (NIR) and 5 (IR) have given good texture results. From the mean results, the tea patches could be well identified. Similarly from contrast, variance and dissimilarity, the boundaries of the tea patches could be observed but thresholding could not be provided to these parameters due to excessive mixing of classes. Though from the mean results the healthy, moderately healthy and diseased patches could be separated but still incurring high mixing among other landuse classes.

The thresholding was given at three levels i.e., 18 to 22 for moderately healthy, 22 to 25.5833 for barren land, 25.5833 to 28.5 for diseased patches and 28.5 to 39.3333 for the healthy tea patches.

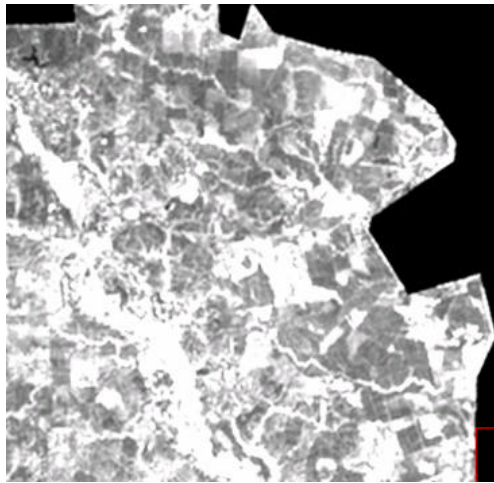


Figure 27: Texture Image (LANDSAT, Dec. 2001)

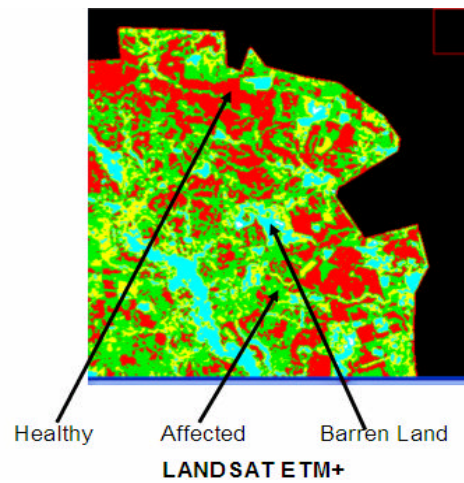


Figure 28: LANDSAT Classified Image

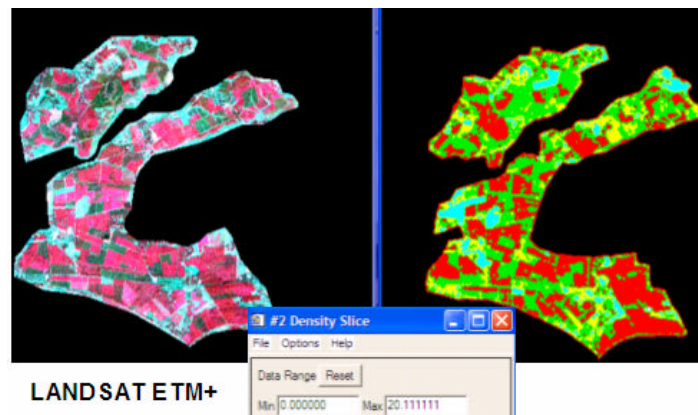


Figure 29: LANDSAT Image showing the Classified Textured Image of Monabarrie Tea Estate

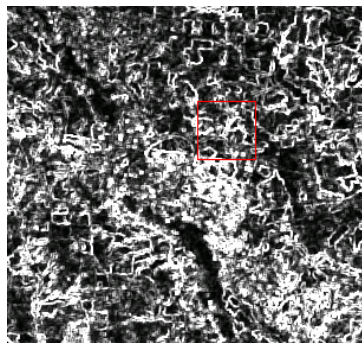


Figure 30: Variance Image

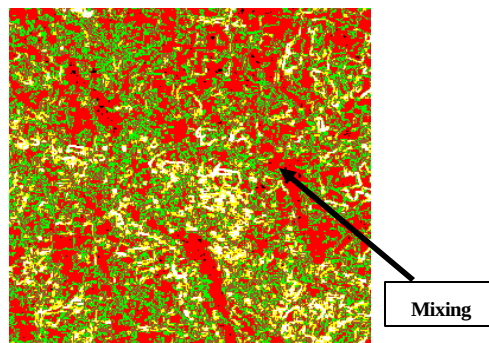


Figure 31: Variance Image (Thresholded)

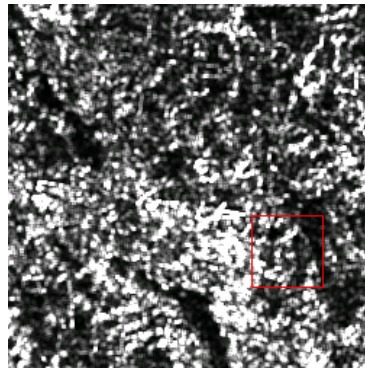


Figure 32: Contrast Image

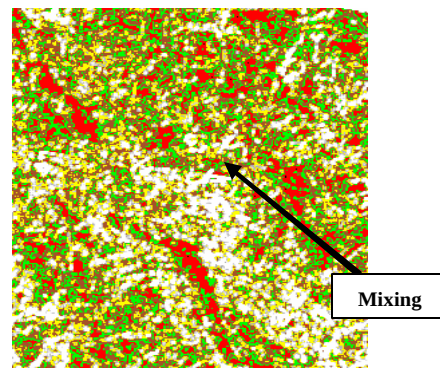


Figure 33: Contrast Image (Thresholded)

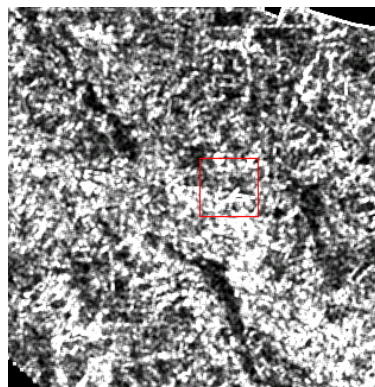


Figure 34: Dissimilarity Image

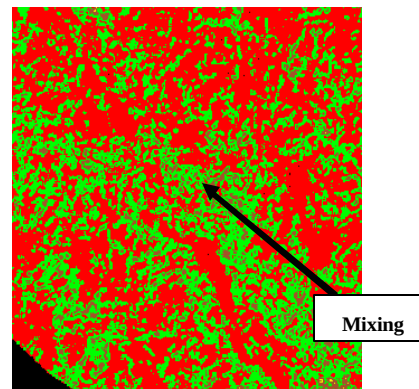


Figure 35: Dissimilarity Image (Thresholded)

Similarly for **LISS III**, Band 3 (NIR) and Band 4 (MIR) gave good texture results with the tea patches prominently identifiable from the mean results while only the dissimilarity, contrast and variance results showed the boundary of the tea patches but when thresholded, lot of inter class mixing could be observed in these parameters. The results for entropy, second's moment and homogeneity did not aid in identification of the classes in the images. The texture images of LISS III were further thresholded to identify between the healthy, moderately healthy and diseased tea patches. The thresholding was given at three levels 14.9444 to 19.6806 for healthy tea, 19.6806 to 23.4157 for affected tea patches and 23.4157 to 29.8889 for barren land. Here moderately healthy and diseased tea could not be separated. So the thresholding was given only for healthy and affected patches (both moderately affected and diseased patches).



Figure 36: Texture Image (LISS III, Feb. 2004)

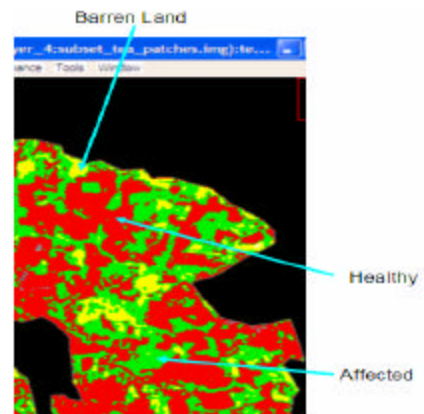


Figure 37: LISS III Classified Image

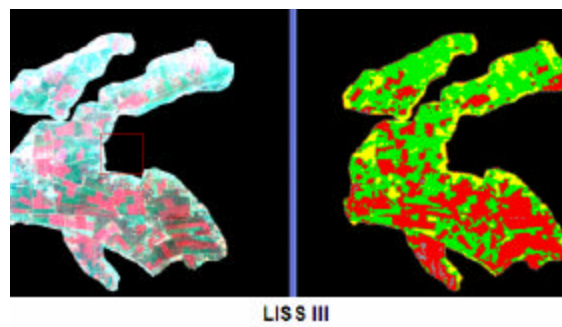


Figure 38: LISS III Image showing the Classified Textured Image of Monabarrie Tea Estate



Figure 39: Variance Image



Figure 40: Variance Image (Thresholded)

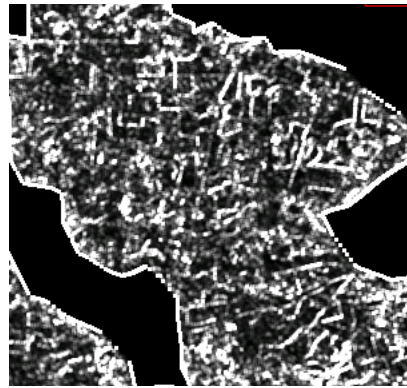


Figure 41: Contrast Image

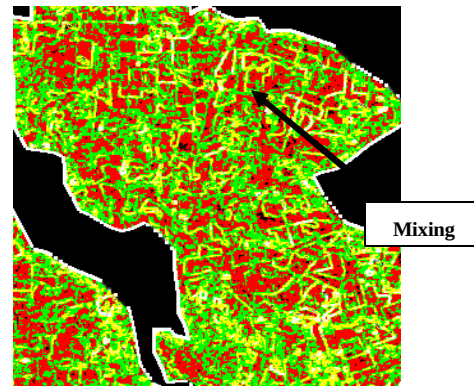


Figure 42: Contrast Image (Thresholded)



Figure 43: Dissimilarity Image

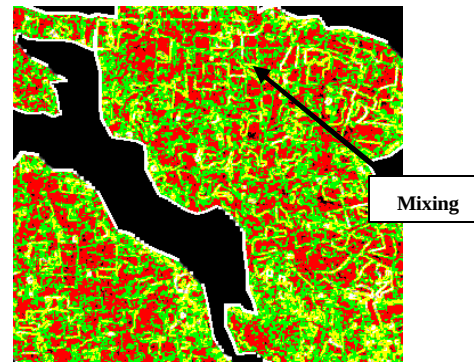


Figure 44: Dissimilarity Image (Thresholded)

In **ASTER**, all the three bands have given good textural results. In the mean results all the three patches could be prominently observed in the three bands. The variance, contrast and dissimilarity showed the boundaries of the tea patches. Once the texture images were generated, the results were compared with the original images. Image thresholding was then carried out at three levels ranging from 22 to 38 for moderately affected patches, 38 to 44 for diseased patches, 44 to 48.85 for barren land and 48.85 to 63 for healthy patches. Only in **ASTER** image, healthy, moderately healthy and affected tea patches could be separated through thresholding. For variance, contrast and dissimilarity, attempt was made to threshold the image but a lot of mixing within the classes.

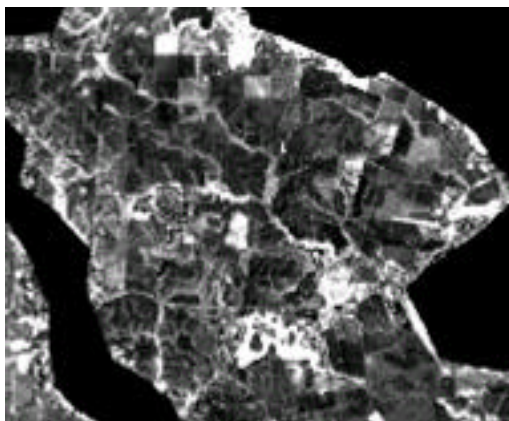


Figure 45: Texture Image (ASTER, June 2004)

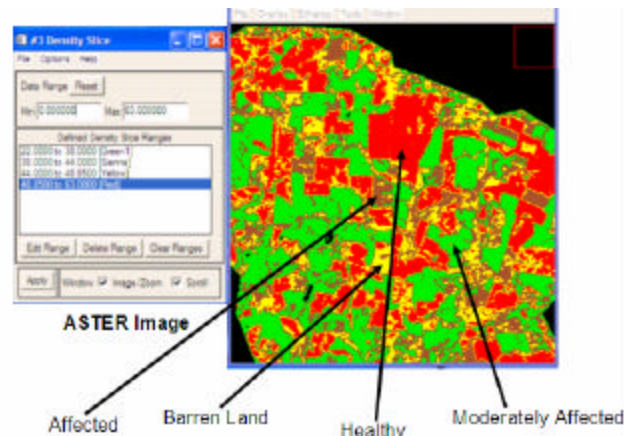


Figure 46: ASTER Classified Image

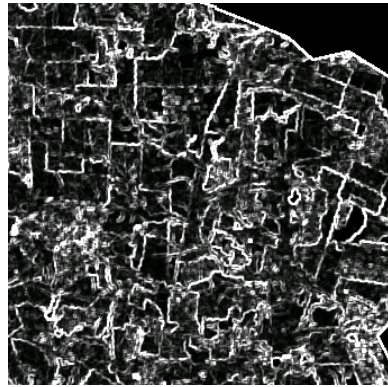


Figure 47: Variance Image

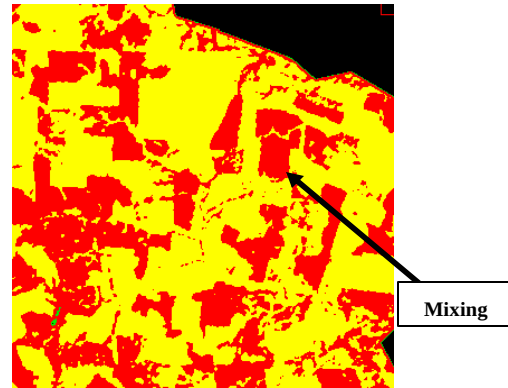


Figure 48: Variance Image (Thresholded)

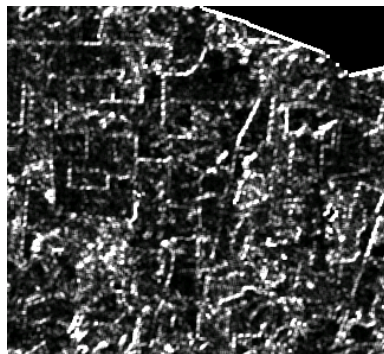


Figure 49: Contrast Image

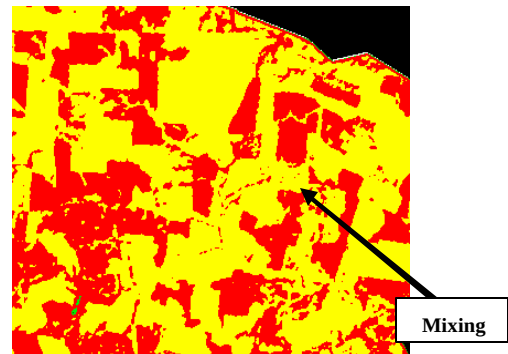


Figure 50: Contrast Image (Thresholded)

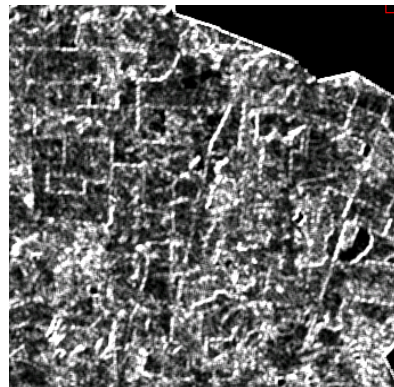


Figure 51: Dissimilarity Image



Figure 52: Dissimilarity Image (Thresholded)

From texture analysis it was clear that thresholding could be provided at two levels to LANDSAT and LISS III while thresholding could be done at three levels in ASTER. In these LANDSAT and LISS III, thresholding into three classes was not possible, because of class mixing. But the mixing in texture was less as compared to the LANDSAT and LISS III and the three tea patches could be easily separated. ASTER therefore gives good textural result. One can also conclude that, for this type of study, the texture analysis should be carried out with high resolution images like LISS IV or IKONOS.

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

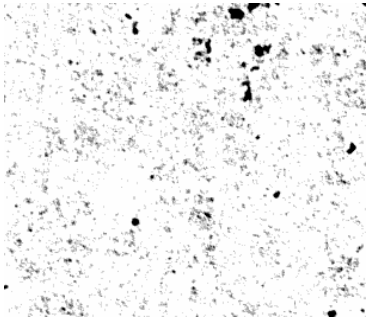


Figure 53: Entropy

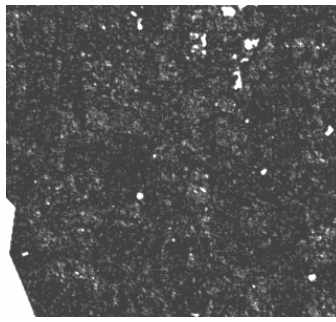


Figure 54: Second's Moment

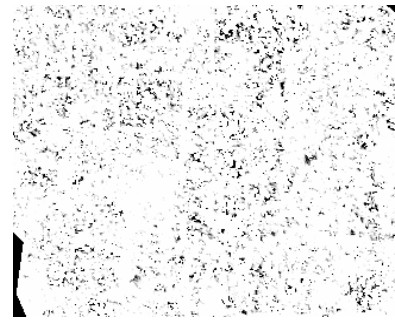


Figure 55: Correlation

5.6. Comparison between Field Leaf Area Index (LAI), Texture Images and Yield

Once the texture images were generated, they were verified using the field LAI values. The LAI values were then overlaid over the texture images and are compared with the FCC of the bands.

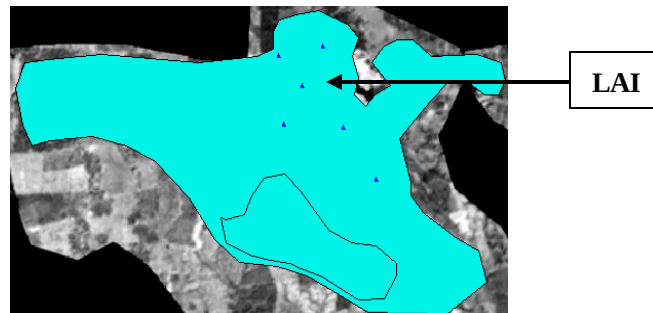
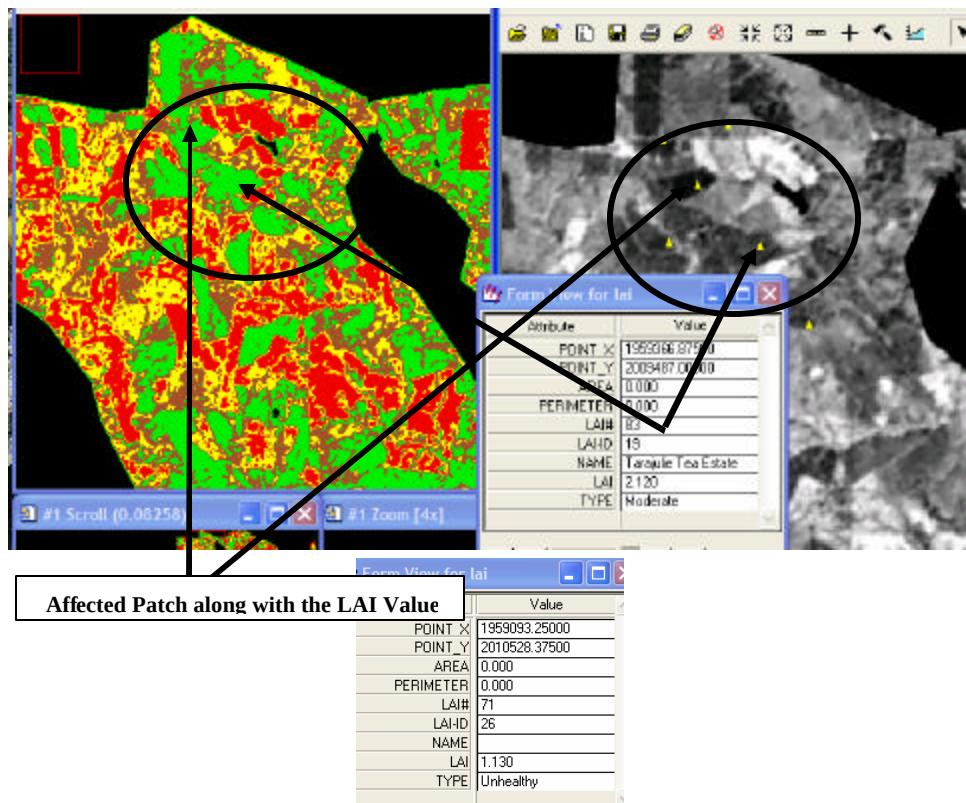


Figure 56: Boundary of Tarajulie Tea Estate and the Field LAI Values Overlaid Over the Texture Image



ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

The field LAI values of Tarajulie Tea Estate ranges from 1.12 to 2.12. The garden is covered by moderately affected and diseased plantations. Comparing the textural analysis results and the LAI values with that of the yield values it can be said that the garden falls in the medium yield category. For a garden to be considered as medium producing, the average annual yield of the garden should be less than 3000 tonnes per year but not below 2000 tonnes. When the results were compared with the yield of the garden from 1994 to 2004 it was observed that there is a considerable reduction in yield during these years. In 1999, the garden recorded a low yield of 1761 tonnes. But still the yield upto last year was found to be above 2000 tonnes. Field LAI values and yield showed that the garden is moderately affected to highly affected garden. For Tarajulie Tea Estate, the graph (**Figure 57**) shows the yield for the last 10 years.

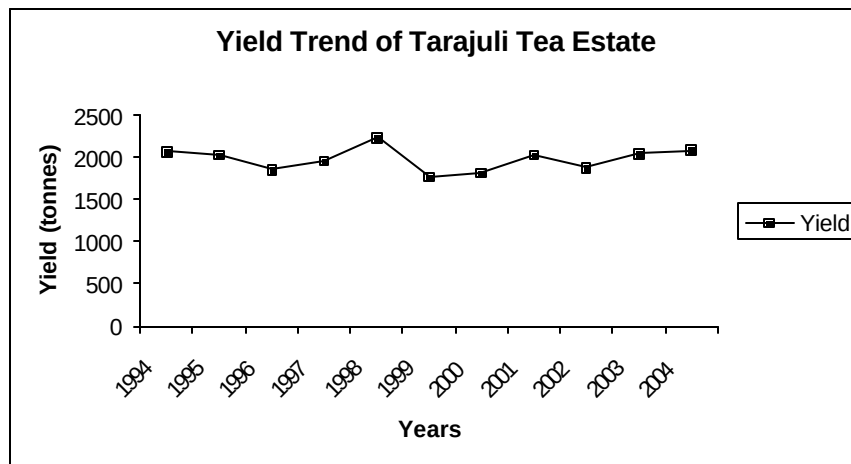


Figure 57: Yield Trend of Tarajulie Tea Estate for Last 10 Tears

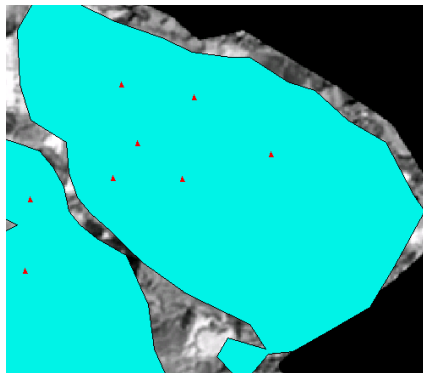
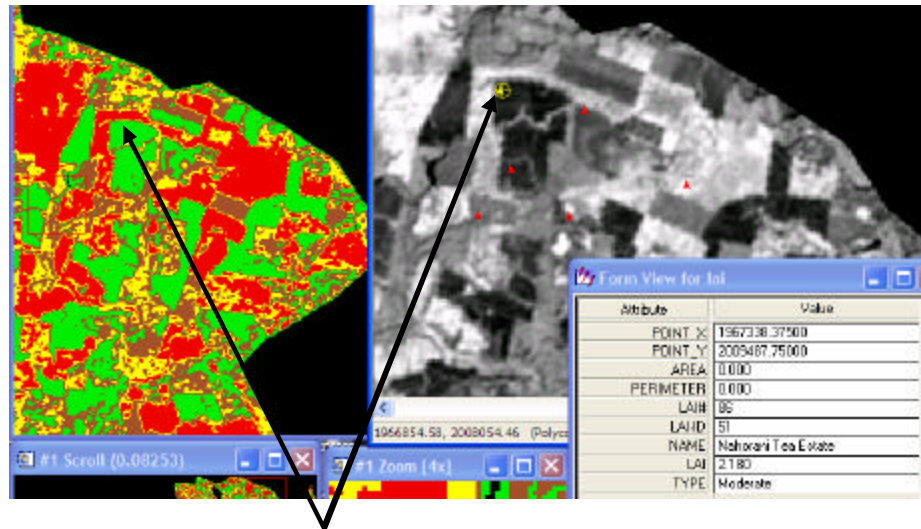


Figure 58: Boundary of Nahorani Tea Estate and the Field LAI Values Overlaid on the Textural Image

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES



Moderately Affected Patch along with the LAI Value

The field LAI values of Nahorani Tea Estate ranges from 2.11 to 2.18. The garden is covered by moderately affected plantations. On comparison of the textural analysis results and the field LAI values with that of the yield values it was clear that it is a low tea producing garden. For Nahorani Tea Estate, it was observed that yield of the garden was below 2000 tonnes for last six years which was well below the average annual yield of 3000 tonnes per year. The decrease can well be noticed from the graph (Figure 59).

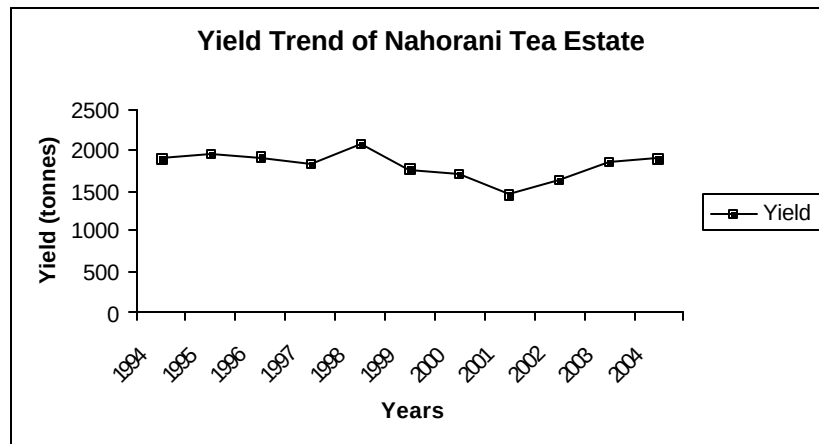


Figure 59: Yield Trend of Nahorani Tea Estate for Last 10 Years

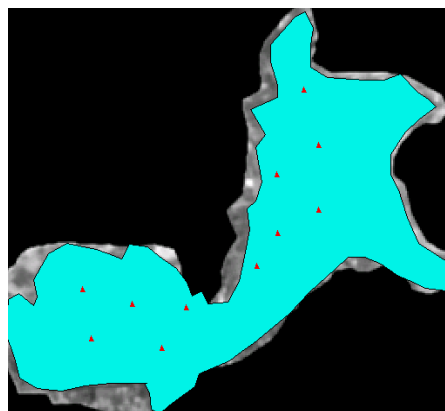
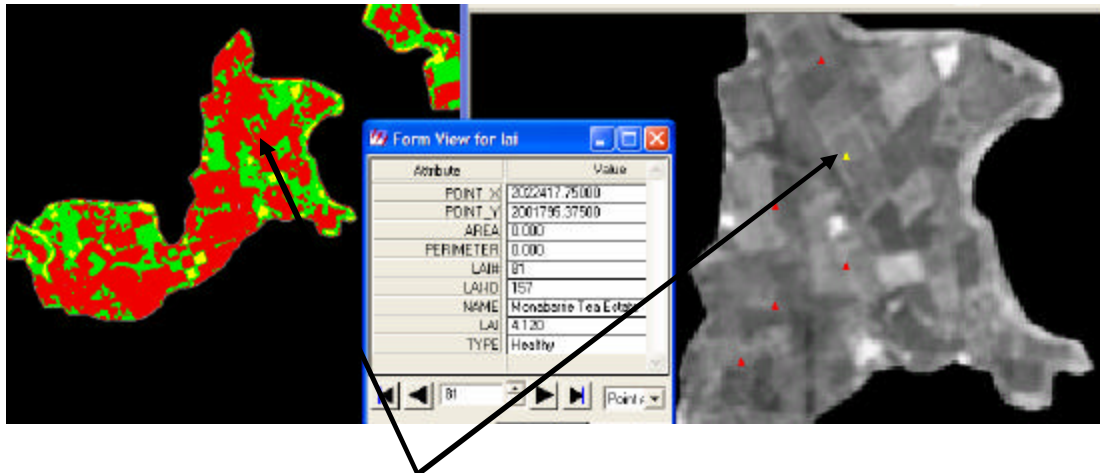


Figure 60: Boundary of Monabarrie Tea Estate and the Field LAI Values Overlaid Over the Texture Image

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES



Healthy Tea Patches along with the LAI Value

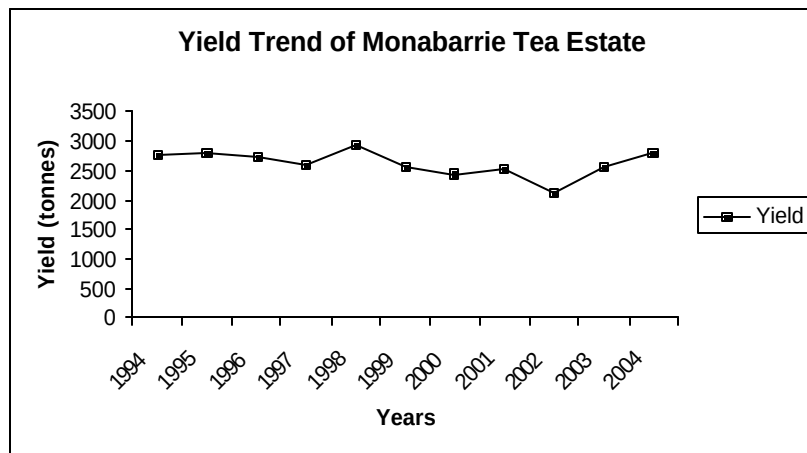


Figure 61: Yield Trend of Monabarrie Tea Estate for Last 10 Tears

The field LAI values of Monabarrie Tea Estate ranges from 3.84 to 4.33. The garden is covered by healthy as well as moderately affected plantations. Comparing the texture analysis results and the LAI values with that of the yield values it was observed that this garden is a high yielding garden. For Monabarrie Tea Estate, the yield is below the average yield of the gardens that is 3000 tonnes per year but almost nearer to the average yield. This shows that the garden yield continues to remain between 2500 and 3000 tonnes per year. From the field visit it was also observed that the garden is very well managed with proper schedule of irrigation, manuring and other management practices.

The diseases in the gardens occurred mostly during the monsoon season (June to November) when there is severe and incessant rainfall. During this time the humidity as well as the temperature is also quite high. All these factors are favourable for the occurrence of the two diseases red spider attack and Helopeltis attack). Tea plants are highly susceptible to these two diseases. Once the disease occurs it becomes difficult to control it as it spreads rapidly. So in such situations it is always better to take precautionary measures at the very initial stages.

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

5.7. A Qualitative Evaluation of The Percentage of Healthy, Moderately Healthy and Diseased Tea Areas

The tea patches were masked out from the landuse/landcover maps for further analysis to find the percentage of healthy tea patches, moderately healthy tea patches and affected tea patches. The formula used for estimating the percentage of affected and non-affected tea is given below:

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

Classes	LANDSAT Image		LISS III Image		ASTER Image	
	Area (Ha)	Area %	Area (Ha)	Area %	Area (Ha)	Area %
Healthy Tea Patches	26737.4084	60.326	17759.366	43.92	6209.888	24.874
Moderately Healthy Tea Patches	10426.0452	23.527	14878.333	36.792	12495.803	50.052
Diseased Tea Patches	7157.8351	16.149	7800.918	19.291	6259.95	25.074
Sum	44321.28		40438.62		24965.64	

Table 8: Table showing the percentage of Affected and Non-Affected Tea Patches

Using the LANDSAT, LISS III and ASTER landuse/landcover image, the area for the individual classes were computed (in hectares). Among the classes, the area of healthy, moderately affected and diseased tea patches were taken into consideration from which the percentage of healthy, moderately healthy and diseased tea patches were calculated. From **Table 8**, the variations in tea plantations at three different dates can be observed. The LANDSAT image of December, 2001 showed 60.4% area under healthy tea, 23.6% area under moderately affected tea and 16.2% area under diseased tea. For the LISS III image of February, 2004, it was found that 43.9% area under healthy tea, 36.8% area under moderately affected tea and 19.3% area under diseased tea. Similarly for ASTER image of June, 2004, area under healthy tea was found to be 24.9%, moderately healthy tea was found to be 50.1% and diseased tea to be 25.1%. From the above statistics it is quite clear that the disease was more prominent in the month of June. From June to October, the weather remains hot and humid accompanied by heavy monsoon showers. This is the peak period for the outbreak of **Red Spider Mite** attack and the **Helopeltis** attack. The tea bushes are highly prone to these two diseases during this period and once the disease breaks out it spreads very rapidly.

5.8. Detection of Affected Plantations from Remotely Sensed Images

From the above results and discussions it is clear that one can easily identify the affected and non-affected tea patches from remotely sensed images. The disease started in the year 1999 but was not severe at the initial stage. During the year 2000 and 2001, there was heavy monsoon showers accompanied by high temperature and humidity. These conditions have favoured the spread of the disease. Between 2003 and 2005 the spread was quite severe. When the LANDSAT ETM+ (December, 2001), LISS III (February, 2004) and ASTER (June, 2004) images were compared, it was observed that there was a continuous shift in the disease from one place to another. The shift was minutely observed in all the images. It was further verified on the field. All the affected tea patches from 1999 to 2005 were identified from the garden records and from the field visit. The field records have shown that there was a rapid shift in the spread of the disease in the gardens. All the spots were visited and marked in the images and compared. From this it was quite clear that whatever has been visually interpreted from the image was correct and the shift in the disease could be well established. Figure 64, 65 and 66 showed the FCC showing the healthy and affected tea patches.

5.9. Yield Estimation

For the yield estimation the MODIS LAI image for August and MODIS NDVI image for April, June and August from 2000 – 2004 were used. 1 x 1 and 3 x 3 kernel pixel extraction method was used to extract the NDVI and LAI values from the NDVI and LAI images. Finally the mean NDVI for all the MODIS images were extracted using the area weighted average or zonal attribute.

5.9.1. LAI Field Observations

The LAI values were collected from the field using the plant canopy analyzer. Sixteen gardens were selected out of which four gardens each were declared as high yielding, medium yielding and low yielding gardens respectively. The LAI reading for each division of the gardens were recorded on the basis of healthy, moderately healthy and affected tea patches. Three LAI observations were taken along with the GPS points and from each observation two readings were recorded. The average of the two readings gave the actual LAI value for the single point. These LAI values were used for observing the LAI variability with the MODIS LAI and NDVI.

5.9.2. LAI and NDVI Relationship

Similarly, MODIS NDVI image was generated and the tea garden patches were masked out. Using the masked NDVI image, the NDVI values were extracted from the tea masked area using 3 x 3 kernel for extracting the pixels. The average of the actual LAI and NDVI values were calculated and the linear regression analysis was carried out using the LAI and NDVI values. The LAI – NDVI values were plotted and linearly regressed. From the analysis it is observed that there exist a linear relationship between LAI and MODIS based NDVI. The relationship was quite weak but yet significant with moderate $R^2=0.40$ value. Thus it could be inferred that MODIS derived NDVI can approximately provide information on leaf area index for tea. The relationship is shown below.

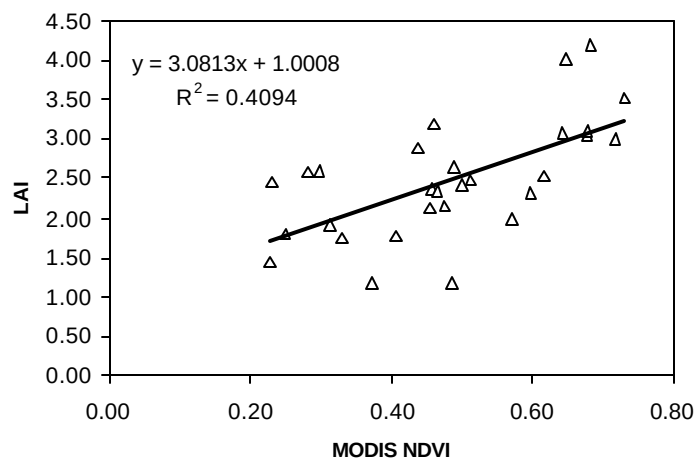


Figure 62: LAI-NDVI Relationship

5.9.3. Relation Between Tea Leaf Yield and MODIS NDVI

Correlation analysis was carried out between area weighted averaged NDVI of tea for selected tea estate with their tea leaf yield for different years (2000-2004). The correlation coefficient 'r' values between yield and NDVI at critical time periods are shown in the table. Results showed that correlation is positive and significant irrespective of month of the NDVI over the years. During 2000 and 2001, tea leaf yield was found significantly related to NDVI at 95% level of significance while during 2003, correlation is positive.

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

Year	NDVI (April)	NDVI (June)	NDVI (August)
2000	0.503*	0.475*	0.440*
2001	0.489*	0.492*	0.469*
2002	0.561**	0.629**	0.520*
2003	0.643**	0.670**	0.680**
2004	0.530*	0.559**	0.553*

*Significant at 0.05% level & **Significant at 0.01% level

Table 9: Year wise correlation between tea leaf yield and MODIS based NDVI of tea estates during different months

Variations could be well observed from the table. There were reasons for such variations. During the year 2000, there was outbreak of disease infestation due to heavy showers accompanied by high temperature and high humidity. This condition is highly favourable for *Red Spider* and *Helopeltis* attack. Apart from this, the ground LAI collected from the field showed lot of variations due to continuous plucking, infestations and also due to un-plucked areas. The different species also showed variations in the LAI readings. But still a significant correlation could be seen between tea leaf yield and MODIS NDVI of tea estates during different months.

5.9.4. Tea Yield Model

Linear relationships between tea leaf yield and MODIS NDVI were developed. Here five years yield from 2000 – 2004 as well as their corresponding NDVI were used for the yield model. The observations were linearly regressed for three different months as shown in the **Table 10**. It was observed that there is a significant positive correlation between yield and NDVI. The variance of 0.243 and 0.292 indicate that there is greater variability in the yield during different periods. Though the R^2 value of the coefficient of determination was found to be less the relationships were significant.

Sr. No.	Equation	N	R^2	SEE	F
1	$1106.06 + 1472.55 * NDVI_{June}$	88	0.243	287.09	27.56
2	$797.29 + 1208.08 * NDVI_{June} + 890.43 * NDVI_{Aug}$	88	0.292	279.24	17.52

Table 10: Tea Leaf Yield Models Based on MODIS NDVI

The significance (probability) of the F value was set at 0.05 level. The entry probability of F value taken is less than 0.05 for significant result. The F probability result shows for all linear regression equation are less than significance F change. There is a close relationship between yield and NDVI. Therefore the Null Hypothesis1 (H_0) which shows that there is a close relationship between yield, LAI and NDVI used for finding the yield variability is accepted while the alternative hypothesis (H_a) is rejected.

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

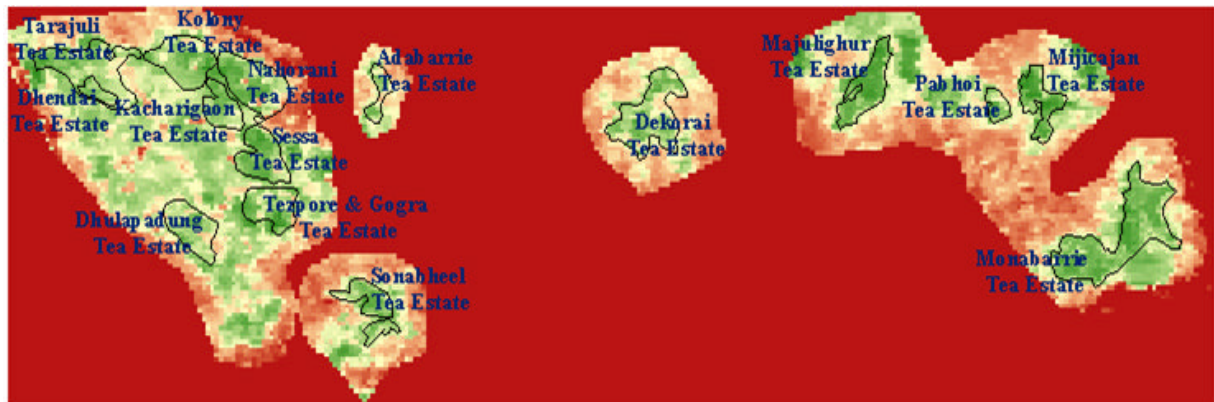


Figure 63: MODIS NDVI Map with the Garden Boundaries

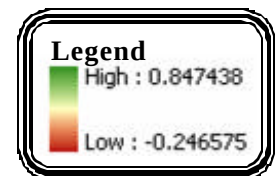




Figure 64: LANDSAT image showing the affected and healthy patches of tea gardens

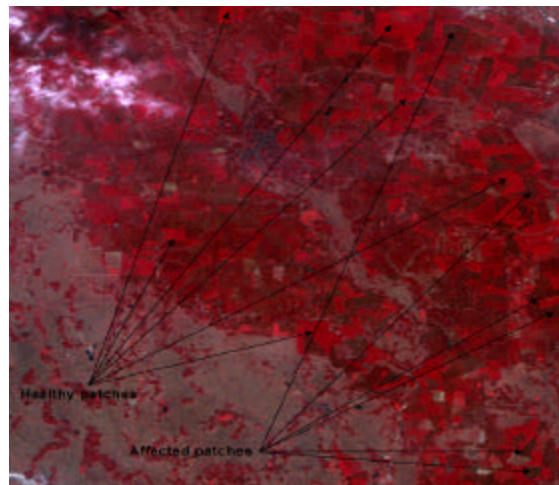


Figure 65: LISS III image showing the garden patches

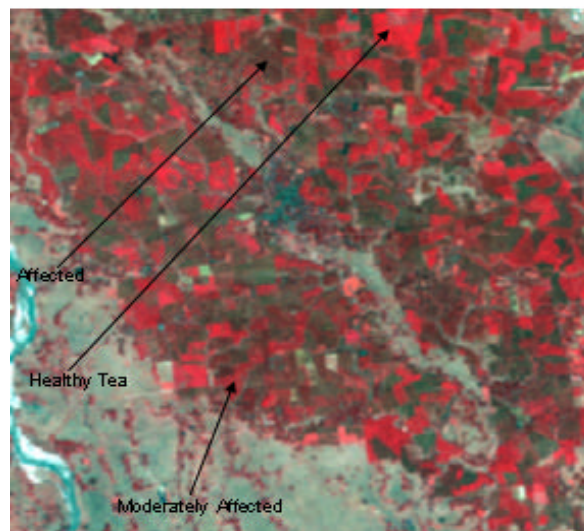


Figure 66: ASTER Image Showing The Tea Garden Patches

6. Conclusions and Recommendations

6.1. Research Questions Concerning The Research Objective 1

The main objective of research is the assessment of tea bush health using texture and tonal variation from satellite imagery of tea growing areas and the effect of bush health on yield.

6.1.1. Research Questions

a. Can tea plants be realistically identified automatically from satellite images like Landsat, LISS III and ASTER?

The prime objective of this question is to identify the tea plants or the tea patches from the LANDSAT (of spatial resolution 30m), LISS III (of spatial resolution 23.5m) and ASTER data (of spatial resolution 15m). From these three datasets the tea patches were identified.

The LANDSAT image showed the diseased, moderately affected and healthy tea patches. Band 2 detects the green reflectance from the healthy tea patches. Band 3 detects the chlorophyll absorption in tea. Band 4 data is ideal for detecting high peaks in healthy green tea patches and for detecting water-land interfaces.

From the LISS III image, the tea patches could be easily identified. Both affected and unaffected patches could be observed from the LISS III image. The Band 2 (Green) is used for tea patches discrimination. Band 3 (Red) showed the chlorophyll absorption of the tea patches. Similarly Band 4 (NIR) shows high reflectance for healthy tea patches and is useful for green biomass estimation and crop vigour.

From the ASTER image, the tea patches could be very well distinguished between healthy, moderately affected and diseased patches. The affected and the unaffected tea patches were very prominently visible. As compared to the LANDSAT and LISS III image, the ASTER image gave much better results. The ASTER data gave the relative spectral reflectance and emissivity, surface radiance, temperature, brightness temperature-at-sensor, and digital elevation models. Band 1 (Green) distinctly discriminate the tea patches. Band 2 (Red) showed the chlorophyll absorption of the two patches. Band 3 (NIR) showed the peak reflectance for healthy tea, moderately affected tea and diseased tea patches. The three classes could be very well identified from the ASTER image.

Once the tea patches were identified, they were verified on the ground and the shift in the disease was noticed.

b. Can we understand the features observed on remote sensing images from field conditions in contexts with the tea planters/farmers?

Once the features were identified in the images, they are then verified on the field. The managers were interviewed about the present status of their tea gardens. The information regarding the yield, management practices, as well as the diseases of the gardens were collected. Further information regarding the time of irrigation and frequency of irrigation were also collected. This information were further compared with the ground information. From the field the ground LAI values were collected using a plant canopy analyzer based on healthy, moderately healthy and diseased patches from each divisions of the garden. The GPS point at that particular LAI was also collected.

c. What is the role of texture and tone in determining tea bush health?

The textural analysis was carried out to identify the three patches of tea such as healthy, moderately healthy and diseased tea. A comparison was made between the classified maps and the texture images. In this study, Grey Level Co-occurrence Matrix (GLCM) was used for studying the texture of tea patches. Texture images were generated taking into account all the texture parameters. These parameters were then analyzed band wise and the parameters giving good texture result were selected. The mean provided

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

better results than the other parameters. For contrast, dissimilarity and variance, however the boundary of the tea patches were distinctly visible. Remaining parameters like the second's moment, homogeneity, correlation and entropy could not produce any good results and so these parameters had to be discarded. Once the texture images were generated, then the thresholding of the images was done at different ranges to generate the classified images. In case of ASTER it was observed that the thresholding could be given to all the three patches of tea (Healthy, Moderately Healthy and Diseased Tea) and they could be well separated out. But in case of LANDSAT and LISS III it was observed that the tea patches could be thresholded at two levels only as healthy and moderately healthy because when the thresholding was carried out at three levels, inter class mixing occurred. Mixing was such that a healthy patch was thresholded as diseased patch or a diseased patch as healthy or moderately healthy patches. It was also observed that proper thresholding was possible only with the mean parameter. For the remaining parameters thresholding was a problem because of excessive mixing.

We could not conclude that texture analysis could be used for studying the bush health of tea plantations and whether the bush health is healthy, moderately healthy or diseased that could be well separated. It was observed that to a certain extent GLCM technique could separate out the affected and non-affected tea patches. But the best texture analysis could then be judged when all the texture techniques are applied to this study and their results are compared. Other than this, the analysis should be carried out in high resolution images like IKONOS, LISS IV, etc. The tonal variations also play an important role for visual interpretation of images into healthy or moderately healthy or diseased tea patches. The different bands give different reflectance values by means of which one can easily identify the different tea patches.

d. How is tea bush health affecting the production or yield of tea plantations?

Present tea scenario is that there is a declining trend in the production of the gardens. There are many factors regarding the declining of tea yield. The problems started in 1999 due to draught leading to sharp production cuts. There was slight improvement in 2000 but again the prices drop down. Many factors were responsible for such sharp cut in production. Biggest problem that most of the tea gardens were facing was the infestations from pests and diseases. But among all the pests and diseases it was observed that **Red Spider Mite** attack and **Helopeltis** was creating havoc in most of the gardens resulting in lower production of tea. These two diseases mostly occur during June when the temperature and the humidity are high and accompanied by heavy monsoon showers. This type of weather is highly favourable for the occurrence of these two diseases. The biggest problem with the two infestations was that they spread very rapidly and controlling them is a big concern for most of the gardens. Though pest control measures have been adopted still the total control of the diseases could not be achieved till date. There were also instances where due to excessive application of pesticides the quality of tea has deteriorated. Production in Assam in 2001 was low as compared to the national average. During the year, prices further declined. Export also dropped by 27 million Kgs and Assam could export only 18 million Kgs of tea. During the field trip when the managers were interviewed it was seen that the severity of disease was more from 2003 and the management were finding it difficult to control the disease due to its rapid shift. When the field was surveyed, certain tea patches could be seen with a severe infestation of the two diseases. The management had already stopped plucking from those areas. The only possibility is replanting of new tea plants. Though a garden needs to produce an average of 3000 ton annually, almost all gardens produced below the average yield. The yield trends for some of the gardens have been shown in the appendix. Using the texture analysis affected and unaffected tea patches were identified and analyzed. It was also observed that the LAI collected from the field gave lower values for the affected patches and higher for the healthy patches. When the LAI values were compared with the texture images it clearly showed the affected and unaffected tea patches. The results were further verified with the yield of the gardens.

e. How can the results obtained be helpful in overcoming the problems of conventional tea practicing methods?

Using the optical remotely sensed data it is possible to observe the affected tea patches. Onscreen visual interpretation is done to assess the affected and non-affected tea patches. The healthy patches were seen as bright red colour while the affected patches were seen as brownish red or dark brown in colour. Identification through the imageries will help the management to take necessary steps the earliest.

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

Management can now identify their area of interest and then take the necessary measures accordingly. It will help the management to identify the spot and go there directly and assess the affect instead of surveying the whole field. Using these images the management can monitor the shift in the disease patches timely saving time and labour.

Given the present rate of affect on the tea plantations it has become very necessary to improve the planning and decision making process of the management so that the situation could be dealt with effectively. Occurrence of pest and diseases takes place frequently so continuous monitoring and assessment is very essential. In order to have long term solutions, efforts should be made to replant the affected tea areas by hybrid and resistant varieties. This will prevent the spreading of the diseases to further areas. Efforts should be made to remove the severely affected tea patches and applying the necessary control measures for moderately affected plants.

- Replanting young hybrid tea plants can help prevent spread of the diseases.
- Proper drainage channels to prevent water logging in the plantation area.
- Proper manuring and pesticide application in time to prevent the outbreak of diseases.

6.2. Research Questions Concerning The Objective 2

The second objective of research is to examine between yield and derived NDVI.

6.2.1. Research Questions

a. Is there any relationship between tea LAI and NDVI using MODIS?

It was observed that there is linear relationship between LAI and NDVI. LAI is a key factor useful in crop growth models that may be derived from the optical remote sensing data. The LAI during the plucking stage is an important variable in tea yield modelling and can also be used in crop reflectance modelling. The relationship between tea LAI and NDVI is very important for developing yield prediction models. In this study, when field LAI and MODIS NDVI were analyzed, a variance of 0.4094 was observed between LAI and NDVI. Therefore it was found that the LAI variability could be observed using the MODIS data.

b. Is there any relationship between NDVI and tea leaf yield at critical periods?

Remote sensing measures specific wavelengths of light that are reflected from the leaves of plants in the field. In addition to light in the visible spectra, light in the near infrared spectrum (NIR, which is not visible with the naked eye and is reflected by the plant) is measured as well. The amount of NIR reflectance is related to the biomass (leaf area) of the plant and the plant's vigor; larger plants with more leaves will reflect more NIR light than smaller plants, just as healthy vigorous plants of a given size will reflect more NIR light than diseased or stressed plants of the same size. The NIR reflectance from a plant can change over time as it encounters stress (such as disease), which can then be used to assist in the identification of a problem with the plant prior to the onset of visual symptoms. Reflectance data can be measured and used to calculate a vegetation index (such as Normalized Difference Vegetation Index; NDVI), which has been found to be correlated to plant size, vigor and yield of crops. In this study, at different critical periods the correlation between NDVI and yield was derived. Though variations could be observed between NDVI and yield, yet a positive correlation was obtained. Variations were mainly due to continuous plucking, different tea species and also due to stress such as diseases. But the study showed that a good correlation could be obtained if the above mentioned parameters could be avoided.

6.3. Limitations

Since the study area comes under the restricted zone, there were some problems of data sharing. In certain cases the management themselves were not willing to share information. Extremist activities in the area (towards Indo-Bhutan border) have also created some problem while collecting the data. Lack of information for all the gardens due to paucity of time is another constraint.

6.4. Recommendation

- Further research should be carried out with different sensors of various spatial, spectral and temporal resolution to do a comparative assessment or analysis. Different texture analysis techniques should be used and the results should be compared with other techniques to find the best suitable technique.
- Assessment of bush health at species level can be carried out using high spectral resolution imageries such as hyperspectral imageries.
- Further research can be carried out by fusing optical and radar images.
- Prior knowledge of the study area is very essential to get good classification results.
- Knowledge based and object based classification should be carried out so that the results can be compared with the texture based classification.
- Time to time monitoring of the plantations is very essential.
- Management should have well established strategies so that effective measures could be taken when the need arises.

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Annexure

Annexure 1: Softwares Used

ERDAS (Earth Resources Data Analysis System):

ERDAS stands for Earth Resource Data Analysis System. This is a well known commercial image processing and GIS software package. It has the capability to process all satellite images. It is a large, complex piece of software with a steep learning curve; however, there is little it can't do when it comes to geomapping.

Imagery is far more than pictures of the earth's surface. It is a valuable source of data that captures actual events at specific times and places in the world so that one can study how the earth changes over time. ERDAS IMAGINE gives the tools to manipulate and understand this data.

With ERDAS IMAGINE, one can benefit from many features including:

- A comprehensive toolbox: ERDAS IMAGINE is a broad collection of software tools designed specifically to process imagery. It allows you to extract data from images like a seasoned professional, regardless of your experience or education.
- Easy to Use: With its large and easy-to-use selection of image processing tools, ERDAS IMAGINE both simplifies and streamlines one's workflow. It also allows one to keep in-house many of the functions that may have needed to outsource before.

ENVI (The Environment for Visualizing Images)

ENVI is a robust easy-to-use image processing system that provides analysis and visualization of single band, multispectral, hyperspectral and radar remote sensing data. It also has the capability to work with vector data and perform basic GIS functionality. ENVI's point-and-click graphical user interface (GUI) makes learning and using the system faster and easier. ENVI is built on IDL, an array-based interactive 4th generation language (4GL).

SPSS (Statistical Software Package)

SPSS is a large and powerful software package offering a wide range of statistical techniques coupled with excellent data management facilities and high quality graphics. It is applicable to many different research fields, though it has particular strengths in the areas of social sciences. It is often described as one of the 'friendliest' statistical packages of its type, with a good graphical user interface and plenty of built-in documentation. Advanced features include powerful data transformation, matrix algebra, macro and scripting facilities. There is no built-in limit on the number of variables and cases forming the data (beyond what the system can handle). It can also produce output in HTML and JPEG format for use in web sites. SPSS is a comprehensive and flexible statistical analysis and data management system. SPSS can take data from almost any type of file and use it to generate tabulated reports, charts, and plots of distributions and trends, descriptive statistics, and to conduct complex statistical analyses.

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

Annexure 2:

Months	2000	2001	2002	2003	2004
January	24.6	24.5	26.2	22.9	25
February	25.6	26.4	25.5	24.1	24.8
March	28.1	30.8	29.8	27.8	28.5
April	30	31	29.9	29.5	28
May	31.7	31.5	29.9	32.2	29.7
June	31.9	32.6	32	32	31.7
July	33.3	34.1	31.6	33.3	30.5
August	31.4	32.9	31.8	33.7	32.6
September	31.6	31.7	33.9	31.5	32.1
October	32.1	31.3	31.6	30	30.6
November	28.3	27.2	30.3	27.5	31
December	26.5	25.5	28.5	25	28.3

Table 11: Showing the Temperature (2000-2004) in °C

Months	2000	2001	2002	2003	2004
January	48	50	44	58	46
February	41	49	48	54	46
March	50	37	37	59	62
April	62	52	49	61	67
May	68	56	62	67	67
June	78	69	71	74	80
July	74	69	78	77	72
August	77	76	77	69	75
September	78	71	67	73	74
October	67	59	67	64	54
November	65	60	58	54	46
December	47	48	51	53	53

Table 12: Showing the Humidity (2000-2004) in %

Months	2000	2001	2002	2003	2004
January	7.3	7.1	6.8	1	7.4
February	14.3	33.1	17.6	26.3	26.5
March	33.4	45.6	136.6	115.8	55.3
April	177.6	202.6	457.7	422.1	309.1
May	462.4	294.9	809.9	777	721.6
June	991.5	636.9	1312	1116.9	1059.9
July	1252.1	965.9	1724.1	1234.9	1793.7
August	1755.3	1717	1884.2	1746.1	2291.2
September	2077.5	1961.6	2007.2	2151	2777.4
October	2222.5	2029.3	2056.4	2310.4	3142.3
November	2236.2	2061.8	2069.5	2340.6	3157.3
December	2245.8	0	0	1	3157.3

Table 13: Showing the Rainfall in mm

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

Annexure 3: Yield of The Gardens

Years	Mijicajan	Tezpur & Gogra	Monabarrie	Majulighur	Sonabheel
1994	2024	2066	2760	2119	2046
1995	1851	1897	2795	2147	1960
1996	2323	1875	2728	2046	2078
1997	1892	1760	2588	1921	1976
1998	2257	1979	2946	2179	2153
1999	1902	1832	2551	1911	1999
2000	1684	1778	2438	1811	1918
2001	1876	1888	2515	2042	1980
2002	1803	1983	2125	2008	2020
2003	1825	2105	2547	1936	2104
2004	1900	2300	2788	1978	2290
Average	1939.73	1951.18	2616.46	2008.91	2047.64

Years	Kolony	Kacharigaon	Nahorani	Addabarrie	Tarajuli
1994	2483	1702	1896	2488	2052
1995	2574	1743	1946	2499	2027
1996	2565	1713	1914	2457	1859
1997	2462	1698	1837	2331	1944
1998	2930	2035	2071	2678	2225
1999	2570	1717	1768	2386	1761
2000	2602	1630	1711	2272	1816
2001	2531	1587	1443	2464	2018
2002	2354	1675	1633	2319	1872
2003	2446	1808	1840	2312	2036
2004	2551	1918	1900	2367	2078
Average	2551.64	1747.81	1814.46	2415.73	1971.64

Years	Pabhoi	Dhendai	Dekorai	Sessa	Dhulapadung
1994	2055	1731	2042	2176	2025
1995	2106	1586	2232	2089	2053
1996	2092	1674	2221	2328	1998
1997	1786	1761	2019	1938	2133
1998	1998	2223	2316	1966	2028
1999	1733	1835	1633	1919	2354
2000	1618	1724	1978	2333	2133
2001	1744	1732	2146	2319	1968
2002	1550	1485	2121	2120	2023
2003	1630	1746	1915	2422	1864
2004	1701	1788	1955	2122	1818
Average	1819.36	1753.18	2052.55	2157.46	2036.09

Table 14: Table Showing the Yield of Gardens

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES
Annexure 4: Table Showing The Error Matrix for LANDSAT, LISS III and ASTER

Classification	Healthy Tea	Moderately Healthy	Affected Tea	Scrubs	Settlement	River	River Bed	Barren Land	Row Total
Healthy Tea	7599	78	89	78	45	73	81	49	8092
Moderately Healthy	112	9996	56	99	49	68	59	47	10486
Affected Tea	93	65	5836	78	53	43	41	23	6232
Scrubs	48	69	82	575	67	75	87	62	1065
Settlement	109	98	87	67	125	92	91	66	735
River	76	45	46	56	64	2112	69	71	2539
River bed	56	53	77	88	77	74	795	80	1300
Barren Land	90	79	98	95	89	65	73	762	1351
Column Total	8183	10483	6371	1136	569	2602	1296	1160	31800

Table 15: Error Matrix for LANDSAT ETM+

Classification	Healthy Tea	Moderately Healthy	Affected Tea	Scrubs	Settlement	River	River Bed	Barren Land	Row Total
Healthy Tea	6980	69	79	87	51	89	93	33	7481
Moderately Healthy	101	8663	59	110	43	71	63	52	9162
Affected Tea	87	69	6001	93	59	36	31	41	6417
Scrubs	55	77	77	723	71	82	91	82	1258
Settlement	99	83	83	77	105	92	83	79	701
River	91	41	49	75	71	2341	73	61	2802
River Bed	53	60	69	112	91	83	795	92	1355
Barren Land	89	81	101	120	97	71	91	573	1223
Column Total	7555	9143	6518	1397	588	2865	1320	1013	30399

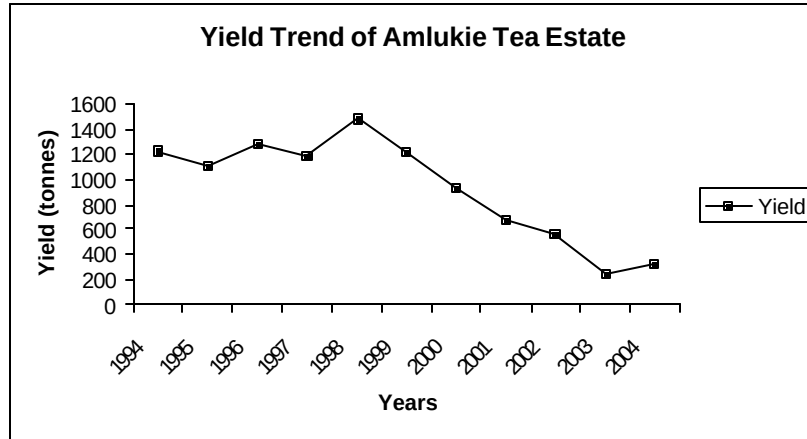
Table 16: Error Matrix for LISS III

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

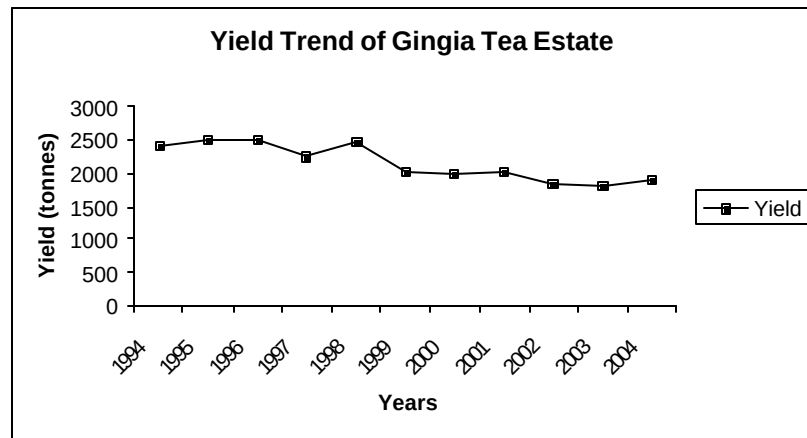
Classification	Healthy Tea	Moderately Healthy	Affected Tea	Scrubs	Settlement	River	River Bed	Barren Land	Row Total
Healthy Tea	7899	78	89	78	45	73	81	49	8392
Moderately Healthy	110	9896	56	99	49	68	59	43	10380
Affected Tea	95	65	5536	78	53	43	41	23	5934
Scrubs	47	69	82	497	67	75	87	57	981
Settlement	102	98	87	63	110	92	91	66	709
River	72	45	46	56	64	2110	69	71	2533
River bed	56	53	77	88	77	74	775	78	1278
Barren Land	88	79	98	92	85	65	73	662	1242
Column Total	8469	10383	6071	1051	550	2600	1276	1049	31449

Table 17: Error Matrix for ASTER

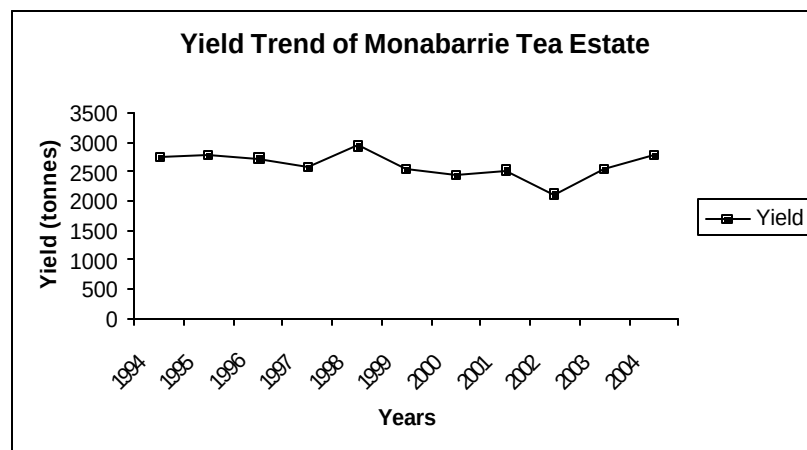
Annexure 5: Graphs Showing The Yield Trend of the Gardens



Low Producing Garden



Medium Producing Garden



High Producing Garden

Annexure 6:

Work Sheet

Information on Majulighar Tea Estate

1. **Divisions of Majulighar Tea Estate:** Majulighar division and Mukhuraghar division
2. **Soil information of Majulighar Tea Estate:**
 - a. Majulighar division: pH=3.14, C%=0.266, K₂O=63, S=21
 - b. Mukhuraghar division: pH=3.79, C%=1.121, K₂O=45, S=34
3. **Time of irrigation:** December to February
4. **Frequency of irrigation:** at 30 days 1 round
5. **NPK dose application (Kg/ha):**
 - a. 133-60-40 (2001)
 - b. 133-60-40 (2002)
 - c. 121-60-40 (2003)
 - d. 154-80-40 (2004)
 - e. 143-90-40 (2005)
6. **Pesticides application:**
 - a. Endosulfan @ 500ml/200 litres of water
 - b. Dicofol @ 500ml/200 litres of water
 - c. Nemazol @ 50ml/200 litres of water
7. **Distance from the road:** 9 Kms
8. **Area of the garden:** 525 hectare
9. **Observations:**

Majulighar division:

Leaf Area Index		Average
Reading 1	Reading 2	
3.11	3.03	3.07
3.12	2.92	3.02
3.23	2.97	3.10

Mukhuraghar division:

Leaf Area Index		Average
Reading 1	Reading 2	
3.43	3.13	3.28
3.13	3.18	3.155
2.96	2.77	2.865

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

Annexure 7: NDVI – LAI Relationship

LAI_ID	Tea Estate	Actual LAI	NDVI	NDVI_3	LAI	NDVI_1	NDVI_3	LAI
1	Kolony Division	2.95	0.75	0.74	2.95	0.75	0.74	3.01
4	Dholkoda Division	2.74	0.73	0.66	2.74	0.73	0.66	3.07
7	Tara Division	2.12	0.39	0.41	2.12	0.39	0.41	1.91
10	Julie Division	1.33	0.48	0.47	1.33	0.48	0.47	1.19
13	Solabari Division	2.95	0.36	0.38	2.95	0.36	0.38	2.89
16	Koilabhatta Division	2.27	0.44	0.48	2.27	0.44	0.48	2.36
19	Malijan Division	3.28	0.51	0.53	3.28	0.51	0.53	3.20
22	Nahorani Division	2.18	0.54	0.56	2.18	0.54	0.56	2.14
25	Hatibari Division	2.18	0.47	0.48	2.18	0.47	0.48	2.17
28	New Adabarrie Division	1.51	0.24	0.24	1.51	0.24	0.24	1.44
31	Balipara Division	2.52	0.20	0.22	2.52	0.20	0.22	2.45
34	Tezapore Division	2.07	0.19	0.31	2.07	0.19	0.31	1.79
37	Gogra Division	2.34	0.24	0.29	2.34	0.24	0.29	2.34
40	Rupajulie Division	2.55	0.61	0.65	2.55	0.61	0.65	2.33
43	Borpukhuri Division	2.46	0.61	0.59	2.46	0.61	0.59	2.43
46	Mijicajan Division	2.66	0.45	0.43	2.66	0.45	0.43	2.66
49	Kolapani Division	2.15	0.59	0.56	2.15	0.59	0.56	1.98
52	Diplongai Division	2.09	0.44	0.40	2.09	0.44	0.40	1.78
55	Monai Division	1.07	0.33	0.34	1.07	0.33	0.34	1.18
58	Dhulapadung Division	3.24	0.29	0.26	3.24			3.14
61	Moinajulie Division	2.83	0.24	0.27	2.83	0.24	0.27	2.58
64	Kacharigaon Division	2.70	0.66	0.67	2.70	0.66	0.67	2.54
67	Topia Division	2.40	0.61	0.58	2.40	0.61	0.58	2.49
70	Monabarrie Division	4.12	0.72	0.70	4.12	0.72	0.70	4.02
73	Behupukhuri Division	4.33	0.67	0.66	4.33	0.67	0.66	4.19
76	Lahorijan Division	3.83	0.79	0.77	3.83	0.79	0.77	3.52
79	Sessa Division	3.13	0.16	0.17	3.13			3.18
82	Namgaon Division	3.48	0.24	0.23	3.48			3.19
85	Majulighur Division	3.07	0.63	0.66	3.07	0.63	0.66	3.06
88	Mukhuraghar Division	3.28	0.73	0.69	3.28	0.73	0.69	3.10
91	Pabhoi Division	2.06	0.34	0.30	2.06	0.34	0.30	1.76
94	Dhendai Division	3.21	0.27	0.30	3.21	0.27	0.30	2.61

Table 18: Table Showing NDVI – LAI Extraction

ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES

Annexure 8: NDVI & Yield Values Used for Tea Model

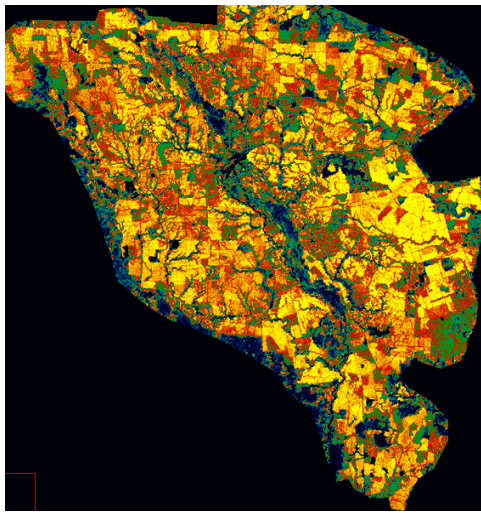
				Yield		
Garden Name	Garden ID	2000	2001	2002	2003	2004
Kolony Tea Estate	4	2602	2531	2354	2446	2551
Majulighur Tea Estate	16	1811	2042	2008	1936	1978
Tarajulie Tea Estate	1	1816	2018	1872	2036	2078
Nahorani Tea Estate	2	1711	1443	1633	1840	1900
Mijicajan Tea Estate	13	1684	1876	1803	1825	1900
Dekori Tea Estate	23	1305	1345	1267	1107	1189
Kacharigaon Tea Estate	5	1630	1587	1675	1808	1918
Dhendai Tea Estate	34	1998	2246	2021	2000	1989
Pabhoi Tea Estate	14	1618	1744	1550	1630	1701
Bamgaon Tea Estate	11	2133	1968	2023	1864	1818
Sessa Tea Estate	30	2333	2319	2120	2422	2122
Monabarrie Tea Estate	15	2438	2515	2125	2547	2788
Tezpore and Gogra Tea Estate	6	1778	1888	1983	2105	2300
Dhulapadung Tea Estate	7	2133	1968	2023	1864	1818
Sonabheel Tea Estate	8	1918	1980	2020	2104	2290
Narayanpur Tea Estate	18	2451	2499	2271	2740	2810
Dhekiajuli Tea Estate2	20	2272	2347	2222	2207	2271

Table 19: Table Showing Yield of the Gardens

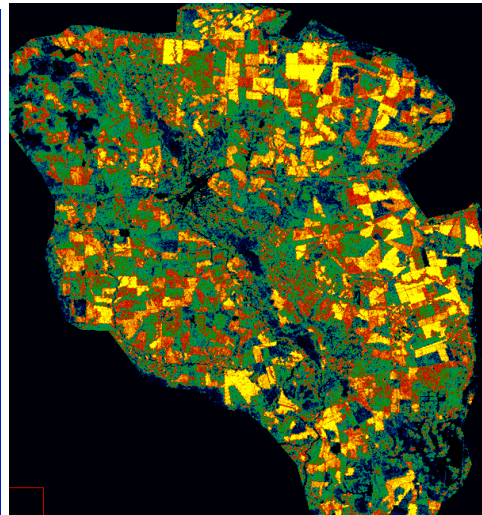
				NDVI		
Garden Name	2000	2001	2002	2003	2004	2005
Kolony Tea Estate	0.590	0.720	0.541	0.544	0.507	0.561
Majulighur Tea Estate	0.448	0.660	0.513	0.492	0.525	0.531
Tarajulie Tea Estate	0.422	0.552	0.402	0.420	0.380	0.399
Nahorani Tea Estate	0.549	0.713	0.538	0.554	0.515	0.550
Mijicajan Tea Estate	0.441	0.672	0.525	0.530	0.521	0.556
Dekori Tea Estate	0.255	0.370	0.285	0.285	0.292	0.299
Kacharigaon Tea Estate	0.559	0.723	0.547	0.523	0.528	0.548
Dhendai Tea Estate	0.589	0.747	0.516	0.529	0.508	0.540
Pabhoi Tea Estate	0.454	0.679	0.552	0.503	0.543	0.563
Bamgaon Tea Estate	0.379	0.521	0.434	0.469	0.435	0.468
Sessa Tea Estate	0.561	0.747	0.561	0.589	0.540	0.576
Monabarrie Tea Estate	0.495	0.725	0.540	0.540	0.556	0.568
Tezpore and Gogra Tea Estate	0.497	0.724	0.551	0.606	0.556	0.569
Dhulapadung Tea Estate	0.471	0.676	0.556	0.549	0.512	0.551
Sonabheel Tea Estate	0.495	0.719	0.572	0.566	0.526	0.568
Narayanpur Tea Estate	0.506	0.719	0.556	0.549	0.513	0.582
Dhekiajuli Tea Estate2	0.479	0.7197	0.59	0.593	0.574	0.594

Table 20: Table Showing the NDVI Values of the Gardens

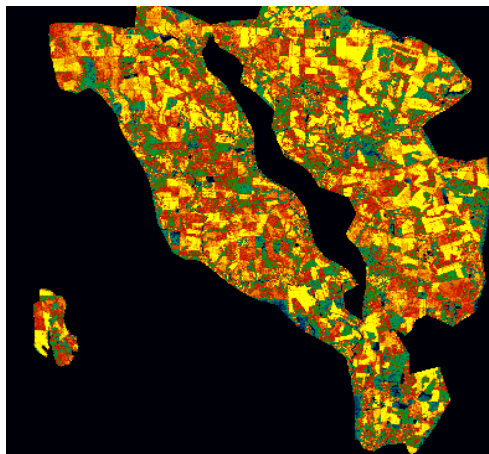
ASSESSMENT OF TEA BUSH HEALTH & YIELD USING GEOSPATIAL TECHNIQUES
Annexure 9: NDVI Images



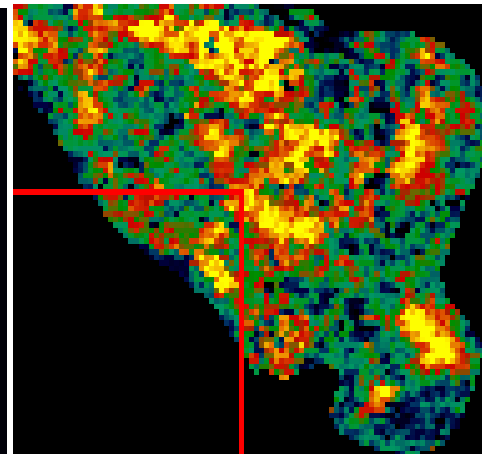
LANDSAT ETM+ (December, 2001)



LISS III (February, 2004)



ASTER (June, 2004)



MODIS (August, 2005)

