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Tea bush health determination and yield estimation

Tapasi Barman

San Jose State University

TEA BUSH HEALTH DETERMINATION AND YIELD ESTIMATION

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Tapasi Barman

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APPROVED FOR THR DEPARTMENT OF GEOGRAPHY

Dr. Gary Pereira

Dr. Richard Taketa

Dr. Stanley Herwitz (UAV Collaborative, NASA Research Park)

APPROVED FOR THE UNIVERSITY

ABSTRACT

TEA BUSH HEALTH DETERMINATION AND YIELD ESTIMATION

by Tapasi Barman

This thesis is an attempt to explore tea bush health by studying and analyzing spectral responses in remote sensing imagery to differences in tea plant quality. The quality production comes from the healthy shoots of the tea plant, and quality commands the highest prices in the tea market. Landsat-7 ETM+ data are studied and analyzed for this research. A field visit was done during the season when shoots mature, and statistical data of Terai tea were vigorously studied and compared to the processed Landsat data. GIS analysis was also carried out to create tea bush health maps and estimation of production. If the health of the tea bush is studied and monitored by management, it could be very profitable for the tea growers as well as the local economy. The remote sensing and GIS methodologies followed in this study proved to be robust, and results closely approximate the growers' statistical records.

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I thank the management of Hansqua Tea estate and Makaibari Tea estates for their time, data and experience they willingly shared, and their valued contributions to my learning during my visit.

I thank my mother and my brother for their encouragement and support in each major step I took in my life. Thank you for always being there for me.

My deep sense of gratitude goes to my husband. Thank you for your patience and loving support. I dedicate this work to you and my mother.

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1.0. INTRODUCTION

The study is conducted for identifying tea bush health and yield estimation. Use of Remote Sensing (RS) and Geographical Information System (GIS) are discussed and analyzed to come up with solutions for effective decision making.

Tea is a hardy, multi-stemmed, slow-growing evergreen shrub which, if allowed, can grow up to seven feet in height. It takes three to six years to mature. During cultivation it is pruned for easy picking (two leaves and the bud are removed by hand) as a low spreading bush to a maximum crop of young shoots (Hadfield, 1974). Tea cultivation in North-East India, Darjeeling district (Terai, Doors and Darjeeling) is mostly of Chinese variety and Chinese hybrids and, to a lesser extent, the Assam hybrid.

Figure 1. Photograph of a young shoot

It is not unusual to find 60 to 100-year-old tea bush growing in many gardens in north Bengal, India. Plucking season begins with the *first flush* of new growth in March and April. Following a short period of dormancy, the plants put forth a *second flush* that is picked from May into June. The summer months bring heavy rains from July until September, yielding a *monsoon flush*. The *autumnal flush* is picked in October and November. The cold winter months of December to February are a period of dormancy. Top grade first and second flush tea leaves bring some of the highest prices found at the tea auctions. Many will not make it to auction because international buyers will pay top dollar, euro or yen for the best offerings. The tea gardens of Darjeeling district are often in a struggle to survive. Aging gardens in Darjeeling as well as in Terai region is one of the main problems facing this 150-year-old industry.

1.1. Background and History of the Darjeeling Tea

Tea (*Camellia Sinensis*) produced in north-east India as well as in Terai region considered one of the highest quality teas in the world (Panda et al., 2002). In the nineteenth century tea cultivation and production in India began at the behest of the British, who ruled India at that time. In the 1830's the British decided to start growing their own tea in one of their colonies, Darjeeling. The tea gardens initiated by them are today located in the northern part of West Bengal and they are divided into Darjeeling tea garden, Terai Tea garden and Doors tea garden.

The gardens are all located at elevations up to over 2000 meters above mean sea level. Due to the unique and complex combination of agro-climatic conditions prevailing in the region tea grown here has a distinctive and naturally-occurring quality and flavor which has won recognition all over the world for well over a century.

1.2. Tea Cultivation

Tea is a perennial crop. Newly planted tea bush requires three to six years to mature and start yielding green leaves. The life of the tea bush is more than 100 years, but the economically useful age of tea bush is less than 100 years; this depends on the type of tea plant, climatic condition and the care received from the planters during its life time. Therefore tea growers cannot turn to crop rotation when the prices are weak nor can the planter increase output in a short time to take advantage of higher ruling prices. The quality of tea also varies from garden to garden and also between the teas manufactured at different times in a particular garden. The green tea leaves of the plant belonging to the species of *Camellia Sinensis* are the source of its natural aroma determined by tea tasters (Bhattacharyya, et al. 2004). The effort of the tea manufacturer is generally aimed at maintaining the natural aroma as much as possible. The final quality of tea depends primarily on the nature and chemical composition of the plucked leaf which is again dependent on the type of bush, the growing conditions and the characteristics of plucked leaf, like coarseness and fineness. Only careful and proper processing will bring out the full potential of the green leaf.

The factors affecting tea quality apart from those involved in processing can be distinguished in three groups: genetic, environmental, and cultural.

(i) Tea quality is primarily determined by the genetic properties of the tea planting in particular in the area.

(ii) Both soil and climate influence the quality of tea. Climatic conditions including temperature, humidity, exposure to sunlight, and rainfall are also important in determining quality.

(iii) Field operations like pruning, fertilizing, shading, plucking round, and plucking standards also play an important role in determining the quality of tea.

1.3. Need for Tea Plant Monitoring

The tea yield is determined mainly by the number of shoots plucked at each harvest and the quality of tea depends on health of the bush and limited use of pesticides and fertilizers. Even certified organic tea is produced in an effort to maintaining its unique quality and aroma in the purest form; Makaibari organic tea from Darjeeling is one of them. Remote sensing could help to identify areas within a field which are healthy or experiencing difficulties, so that preventive measures can be taken. For instance, the correct type and amount of fertilizer, pesticide and need for irrigation if necessary can be decided. Using this approach, the management committees could improve not only the quality and productivity but also help reduce farming costs and minimize environmental impacts. If the data are georeferenced, and if the planter has a GPS (Global Positioning System) unit, precise location of the healthy and stressed plants can be found by matching the coordinates of a given location to that on the image. Detecting tea bush locations and monitoring tea health requires moderate to high-resolution imagery and multispectral imaging capabilities.

1.4. Problems in Tea Cultivation

The annual average tea prices in Indian auctioned during 2000 registered a decline of Rs 11.08 per kg, which was a 15.23% decline from 1999. The average price in 1999 had also shown a drop compared to 1998. The downward trend in tea prices can be noticed from the beginning of 1999. The overall North India auction price has shown a decline of 12.69%, with a decline of 17.03% at Siliguri and 8.48% at Kolkata. The statistical study conducted by the tea board indicates a fall period in the price between the periods of 1999-2000. The statistical data for production and total area under tea garden in Terai region are compared with imagery results in this thesis.

1.5. Objectives

The objective of this research is the formation of a unified approach in identification and estimation of tea health and yield. Research conducted in the field focused on the monitoring of tea plant health and production and how it affects the tea industry in India. Remote sensing can be used to analyze conditions and come up with solutions that could be shared with the tea garden management for effective decision making in the near future and help maximum profit for the tea industry.

1.6. Research Questions

This study is intended to address the following questions:

i. Can tea plants be realistically identified from easily procured satellite images?

ii. How helpful are the spectral signatures in the assessment of the features on the ground in the context of tea canopy characterization?

iii. Is there any relationship between vegetation index NDVI and tea leaf yield?

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

v. How does the health of the tea plants affect yield as well as the regional tea market?

2.0. STUDY AREA

The study area Hansqua tea garden lies in Darjeeling district. The Darjeeling district lies between Latitude 26°31′ and 27°13′ North and Longitude 87°59′ and 88°53′ East, in India (Figure 2) and northern part of the state of West Bengal (Figure 3), and is surrounded by neighboring states of Assam, Bihar, Meghalaya and Sikkim, as well as the nations of Bangladesh, Bhutan, and Nepal.

2.1. Location

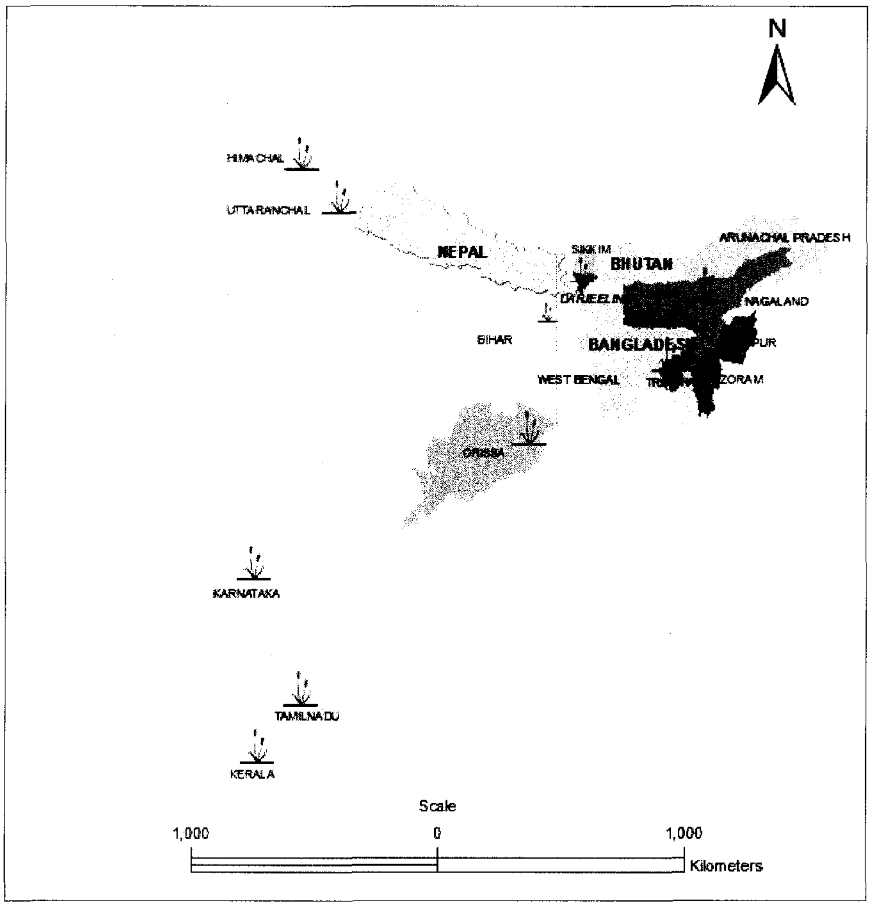


Figure 2. Location map of Darjeeling district within India

Map of West Bengal and Darjeeling District

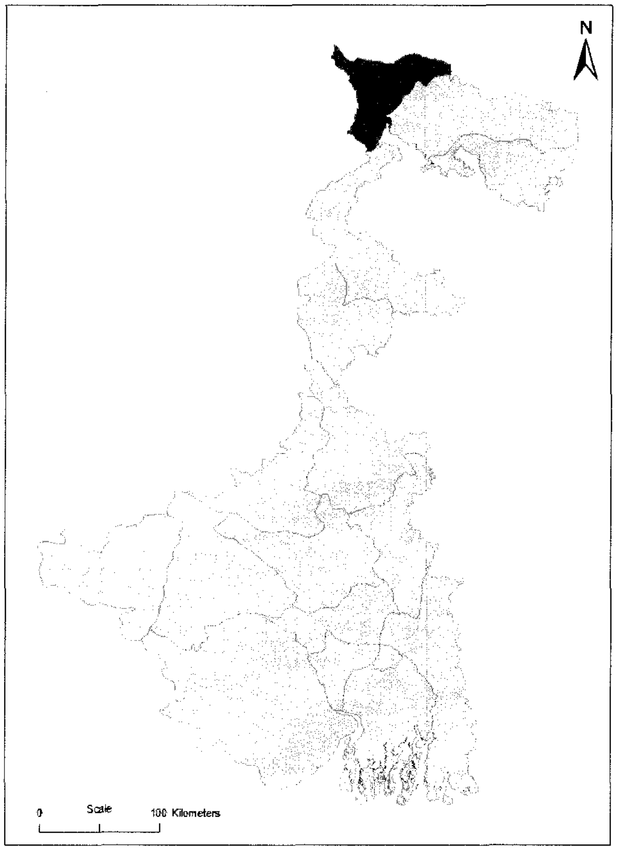


Figure 3. Location map of Darjeeling district within West Bengal

2.2. Geographical Conditions

Relevant geographical conditions can be summarized in terms of the following four variables:

Altitude	700 to 2000 meters
Rainfall	Minimum of 50″ to 60″ annually
Humidity	Very high

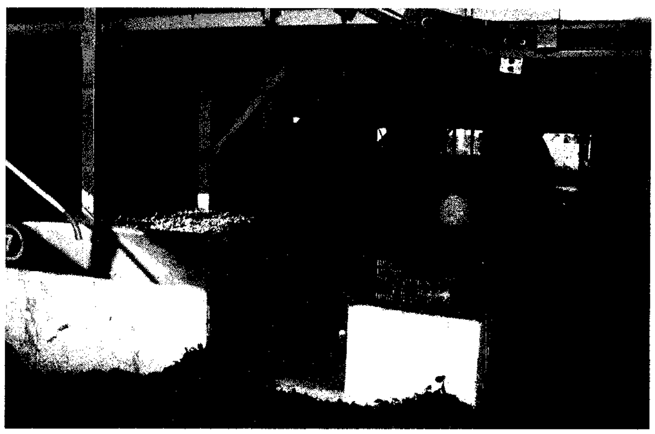
Soil Rich and loamy soil. In the uplands it is usually red and gritty and is residual i.e. derived from the weathering of underlying rocks and rich in organic matter from the surrounding forest cover.

2.3. Photographs of Tea Garden

The following photographs (Figures 4 through 5) were taken during the field visit to the study area, particularly inside the Hansqua Tea garden, in November 2007. The tea plants are often grown in conjunction with Sal trees that provide a partial shade canopy and also the terrain of this region. These factors can influence the results of remote sensing analysis.

Figure 4. Terai tea garden

(a)



(b)

(c)

Figure 5. Hansqua tea garden; (a) Tea bush of Hansqua garden, (b) Hansqua tea factory, (c) Packed tea of Hansqua tea garden.

3.0. DATA AND MATERIALS

The data used for this study are: Landsat-7 ETM+ remote sensing data, toposheet map data, field survey data, and recorded data of the Tea Board of India.

3.1. Remote Sensing Data

Landsat-7 ETM+ data were obtained from USGS archives for the study area: row 139, path 42. Images for the year 1990 and 1999 were used for this study. Both images were taken during November, which is the time when the tea shoots are matured and ready for plucking which is done manually by hand. Table 1 provides an overview of the nominal characteristics of the Landsat-7 ETM+ instrument.

Table 1. Band designations of Landsat-7 ETM+

Enhanced Thematic Mapper Plus (ETM+)	Landsat-7 ETM+	Wavelength (micrometers)	Resolution (meters)
	Band 1	0.45-0.52	30
	Band 2	0.52-0.60	30
	Band 3	0.63-0.69	30
	Band 4	0.77-0.90	30
	Band 5	1.55-1.75	30
	Band 6	10.40-12.50	60
	Band 7	2.09-2.35	30
	Band 8	.52-.90	15

3.2. Toposheet Map

A toposheet map for the area was referenced to delineate approximate garden boundaries. Stippled regions in Figure 6 portray tea growing regions.

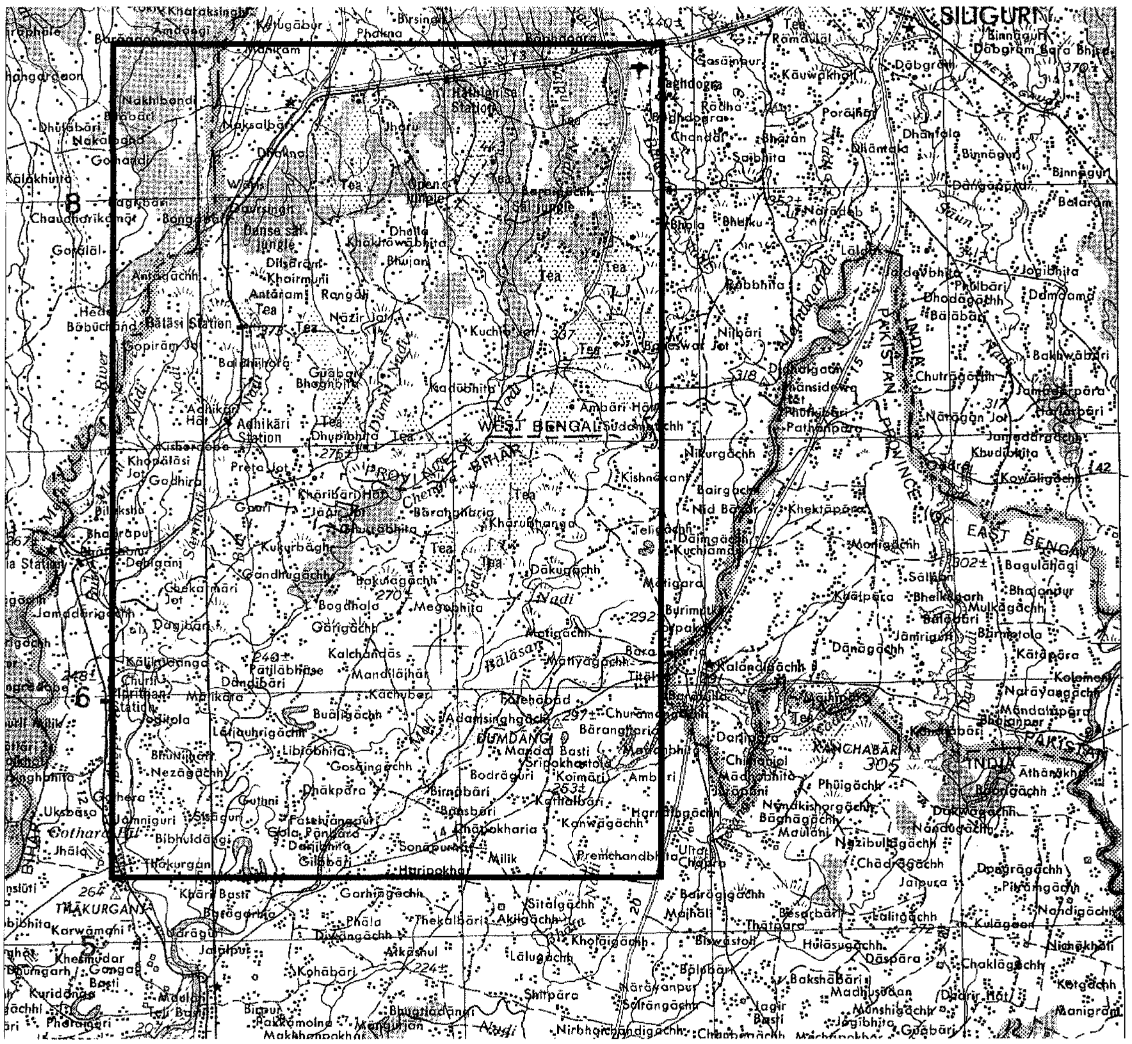


Figure 6. Toposheet Map of Darjeeling district, scale 1:250000.
The green dot patches shows tea plantation area.
Source: U.S. Army Map Service 1955. Reference: NG 45/7. Series U502

3.3. Field Survey and Statistical Data

A field survey was conducted during the month of November in 2007, coinciding with the season when the images were actually captured. Tea bush are seasonal hence the timing is important for analysis and conclusions. Sample locations within the Hansqua tea garden were characterized and photographed in terms of tea health.

3.3.1. Ground Truth Data Collection

Ground truth data were collected using a handheld GPS for establishing the geographic coordinates of the gardens. The readings were then checked and converted as necessary to use for image analysis. While these 2007 observations do not coincide with the 1990 and 1999 Landsat data, they are nevertheless useful for establishing garden locations and characterizing the nature of varying tea health.

3.3.2. Photographs of Tea Bush

Ground-level photographs were taken using a 7.1 mega pixel camera, the timing being mid to late November when actually the bush are matured and ready for plucking shoots. Representative photographs of healthy, moderately healthy, and unhealthy tea are shown in Figures 7, 8 and 9.

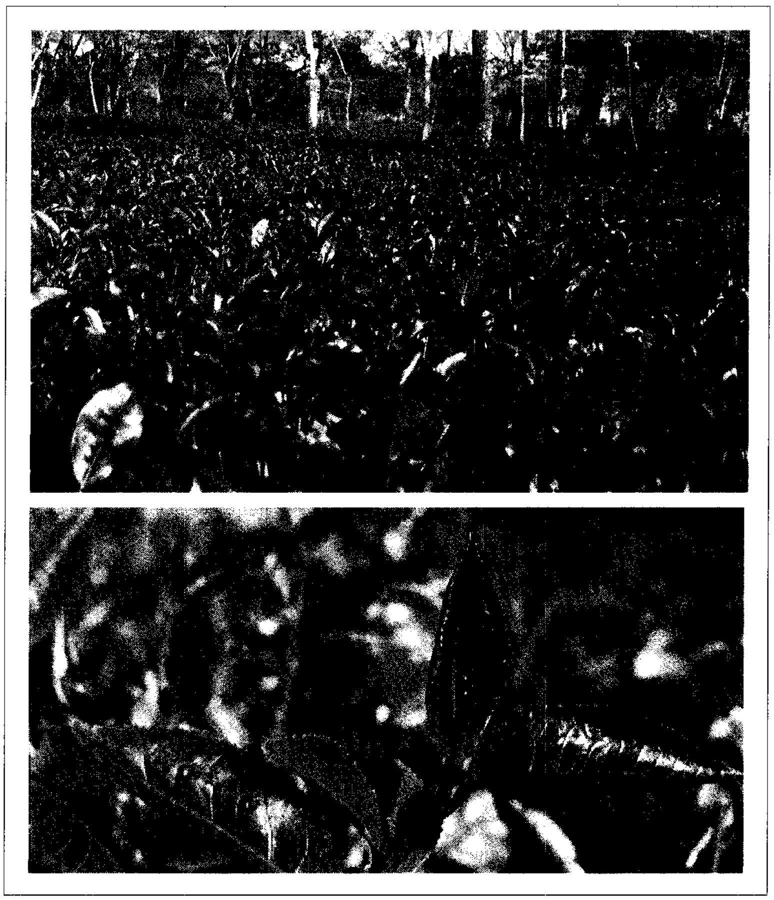


Figure 7. Healthy tea bush

Figure 8. Moderately healthy tea bush

Figure 9. Stressed/unhealthy tea bush and leaves

3.3.3. Statistical Data

Data were collected from the Hansqua Tea garden manger's office as well as the Tea Board of India for validation and comparison of the image analysis results.

3.4. Software Used

Principle software used for this study included: (i) IDRISI 2 & IDRISI Andes, (ii) ERDAS IMAGINE 9, and (iii) ARC VIEW 9.2. This required extensive data conversion between platform types. IMAGINE was used primarily for the conversion of data obtained from USGS archives. IDRISI was used primarily for data transformations in the analysis phase. ARC VIEW was used for extraction of tea data from toposheet data, and for map production.

3.5. Data Preparation

Landsat-7 ETM+ data for the years 1990 and 1999 were studied. The TIFF and FAST format scenes were imported using IMAGINE for further analysis and the study area was clipped out in IDRISI environment. The latitude and longitude coordinates of the study area were checked with toposheet map and with Google Earth results, and also compared with the GPS readings taken during the field surveys.

3.5.1. Georeferencing the Images

The images of each band are reprojected from reference system UTM-45n and units "meter" to latlong reference systems with units "degree" using IDRISI image processing software. The resulting data files for 1990 and 1999 hold the following characteristics:

Reference system/Projection:	LATLONG
Data Type:	24-bit RGB
Reference Unit:	Degree
Minimum X:	88.1510657
Maximum X:	88.3429048
Minimum Y:	26.4084014
Maximum Y:	26.6888775

3.5.2. Subset of the Study Area from Landsat Image

The garden area was delimitated from the full image scene using IDRISI software (Figure 10). The spatial features are identified and reference coordinates were checked with toposheet (Figure 11) and GPS readings taken during the field visit.

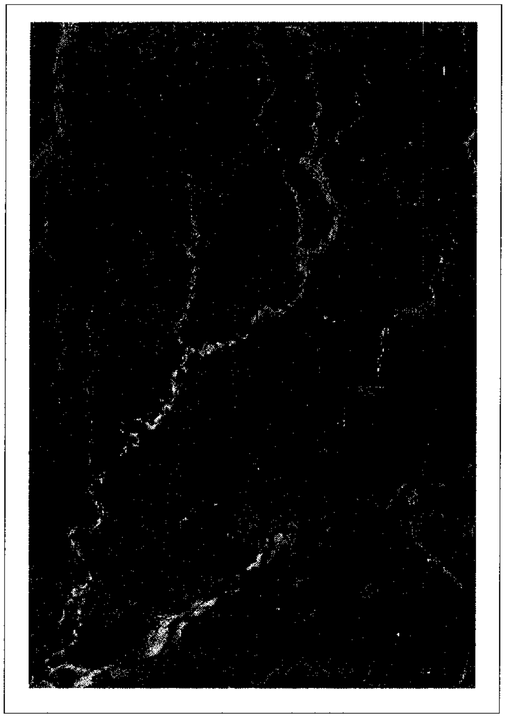


Figure 10. Landsat-7 ETM+
False color image of study area.

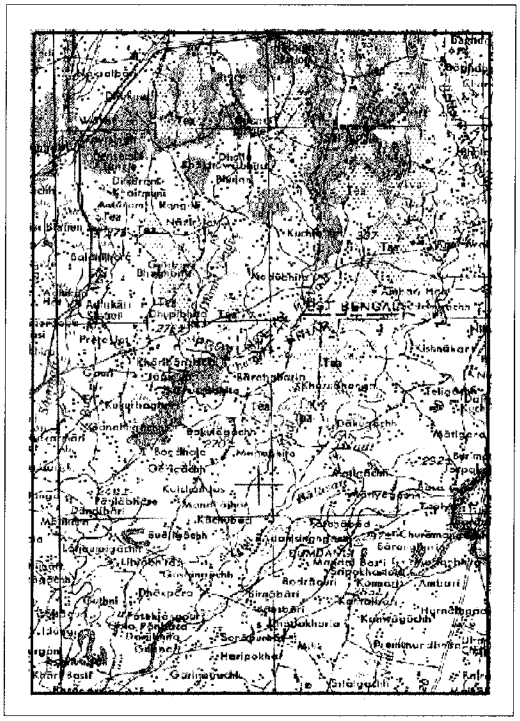


Figure 11. Toposheet Map of
of study area.

3.6. Spectral Signature Analysis

The spectral reflectance of tea plants can indicate variations of signature with respect to the:

i) phenology (each shoot is divided into three phases corresponding to the resting, quiescent and bud-burst phases),

ii) plant type, and

iii) tea health

Healthy vegetation contains large quantities of chlorophyll, which gives most vegetation its distinctive green color. In referring to healthy crops, reflectance in the blue and red parts of the spectrum is low since chlorophyll absorbs this energy; in contrast, reflectance in the near-infrared (NIR) 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 plant stress. The detection of chlorophyll content and greenness in plant is the basis behind some vegetation indices, including the NDVI (Rajapakse et al. 2001), the Wetness component of the Tasseled Cap Transformation, and the Normalized Difference Moisture or Water Index (NDMI or MDWI). The use of each of these indices is examined and shown here.

3.6.1. NDVI (Normalized Difference Vegetation Index) Analysis

Vegetation indices are arithmetic transformations aimed at simplifying data from multiple reflectance bands to a single value correlation to physical vegetation parameters. The most commonly used of theses indices is the Normalized Difference Vegetation Index (NDVI) used by researchers for extracting vegetation abundance from remotely sensed data. It divides the difference between reflectance values in the visible red and near-infrared wavelength to give an estimate of green vegetation abundance. NDVI is (Jensen. 2007):

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

In this study, the NDVI transformation is done for the Landsat-7 ETM+ images for different dates. The NDVI image is analyzed along with RGB and false color composite image.

3.6.2. Tassled Cap Transformation

The TASSCAP in IDRISI undertakes a "Kauth-Thomas" tasseled cap 4-dimensional transformation on 6 bands of TM data (excluding the seventh thermal band) to extract three new index bands, which are designated Brightness, Greenness and Wetness. The Brightness band commonly characterizes soil brightness. The Greenness band highlights green vegetation cover or biomass above ground. The Wetness band provides subtle information concerning the moisture status of the wetlands environment. For a Landsat image, these three bands are calculated from the original six bands for each pixel by means of the following formulas (Jensen. 2007).

Brightness = (TM1*0.3037) + (TM2*0.2793) + (TM3*0.4343) + (TM4*0.5585) + (TM5*0.5082) + (TM7*0.1863)

Greenness = (TM1*-0.2848) + (TM2*-0.2435) + (TM3*-0.5436) + (TM4*0.7243) + (TM5*0.0840) + (TM7*-0.1800)

Wetness = (TM1*0.1509) + (TM2*0.1793) + (TM3*0.3299) + (TM4*0.3406) + (TM5*-0.7112) + (TM7*-0.4572)

These three bands are also considered in this study for the analysis of tea bush. During the bud-burst phase, the garden is greener compared to the surrounding areas; unique values can be found in the derived indices using the Tassled Cap method.

3.6.3. Normalized Difference Moisture or Water Index (MDWI)

The NDWI, based on the near and middle-infrared bands, highly correlates with vegetation water content. Water stress of tea plant can be tracked from NDWI transformed image results and can be validated with Tassled Cap resulted moisture index for studying tea bush health (Jensen. 2007):

$$\text{NDWI} = \frac{\text{NIR}_{\text{TM4}} - \text{MidIR}_{\text{TM5}}}{\text{NIR}_{\text{TM4}} + \text{MidIR}_{\text{TM5}}}$$

3.6.4. Composite Bands and Visual Interpretations

True color and false color compositions were prepared for an initial visual interpretation of images. Images for 1999 are shown in Figures 12 and 13. True color imagery portrays a region as the human eye would see it. False color (specifically, color infrared) imagery assigns the color red to the near infrared band, rather than the red band. This results in the portrayal of vegetation in shades of red, rather than green. In this study the Landsat-7 ETM+ remote sensing images taken on different dates were used to see variations in the locations and extents of tea plantation areas.

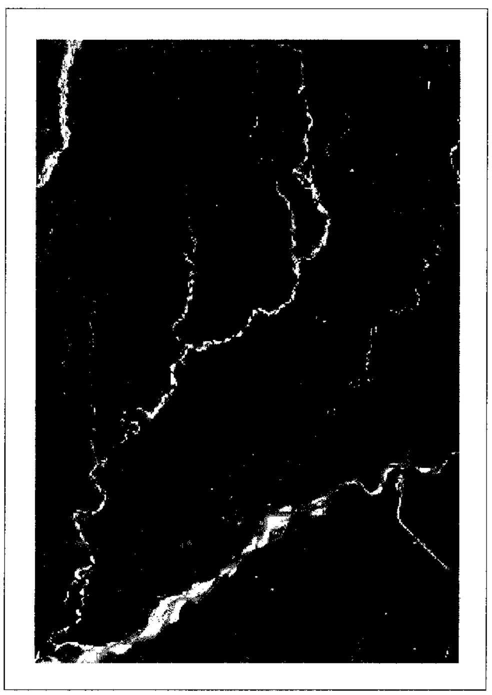


Figure 12. True color composite band (3,2,1).

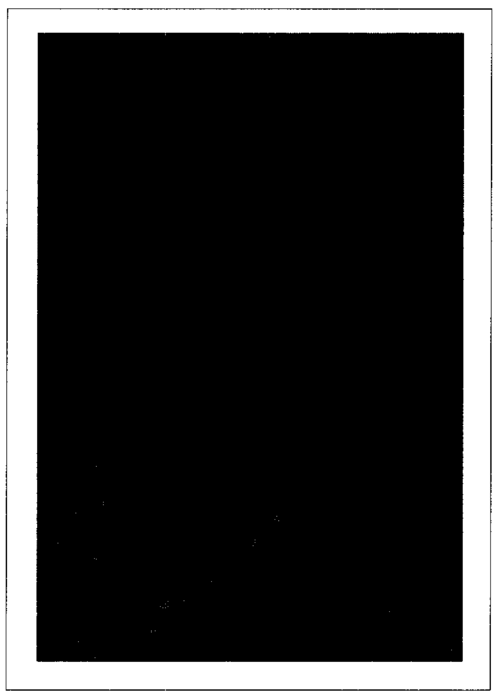


Figure 13. False color composite band (7,5,4).

3.6.5. Image Processing and GIS Analysis

Unsupervised image classification was conducted for extracting natural clusters (in IDRISI environment) of similar pixel values in the image. A user defined post-classification assignment of particular clusters to a tea class was used to select regions in the NDVI images for further analysis. The final interpretation is the result of identification of features, field verification, map preparation and data validation.

Because an unsupervised ISODATA algorithm was used, spectral classes obtained for 1990 and 1999 images were not initially identified. The identification of tea-growing regions was established by comparing the ISODATA classification with the Toposheet map assignments. The particular ISODATA clusters that corresponded to tea-growing regions were then taken as a refinement of the actual locations of tea plantations. Further user-defined reclassification of tea into healthy, moderately healthy, and stressed categories was done by establishing threshold pixel values in the corresponding NDVI image. Contiguous regions of similarly-classified pixels were then extracted, with each assigned a unique identifier, referred to as an "integer image". Area measurements were then performed within IDRISI using GIS analysis to calculate tea bush area using a database query "Area" tool. This tool measures the areas associated with each integer value on an integer image. Area for similar pixel values was obtained and finally the statistical values were validated with the computed image and GIS analysis result for tea yield estimation.

3.6.6. Regression Analysis

Linear regression is used to explain tea health analysis. The result is represented by scatter plots of NDVI vs. NDMI, and various combinations of Tasseled Cap bands vs. NDVI and NDMI vs. Tasseled Cap bands.

The attribute values follow a linear pattern, then there is a *high linear correlation*, while the data do not follow a linear pattern, there is *no linear correlation*. If the data somewhat follows a linear path, then we say that there is a *moderate linear correlation*. Regression is used here to help establish which indices may provide similar or redundant information, and which provide different, uncorrelated information.

4.0. QUALITATIVE IMAGE ANALYSIS AND RESULTS

The methodology used in this study are divided into a qualitative phase, which seeks to establish regions of tea cultivation in terms of tea health categories, and a quantitative phase, which seeks quantitative estimates of areas for each category, estimates tea yield, and compares the results with the statistical data. The qualitative phase is described in this section and results discussed in section five of Tea bush health mapping. The quantitative phase is described in section six and section seven.

To initially detect and examine the healthy and stressed tea patches, different bands as well as true color and false color compositions are compared and discussed here.

A graphical portrayal of the full methodology is shown in Figure 14.

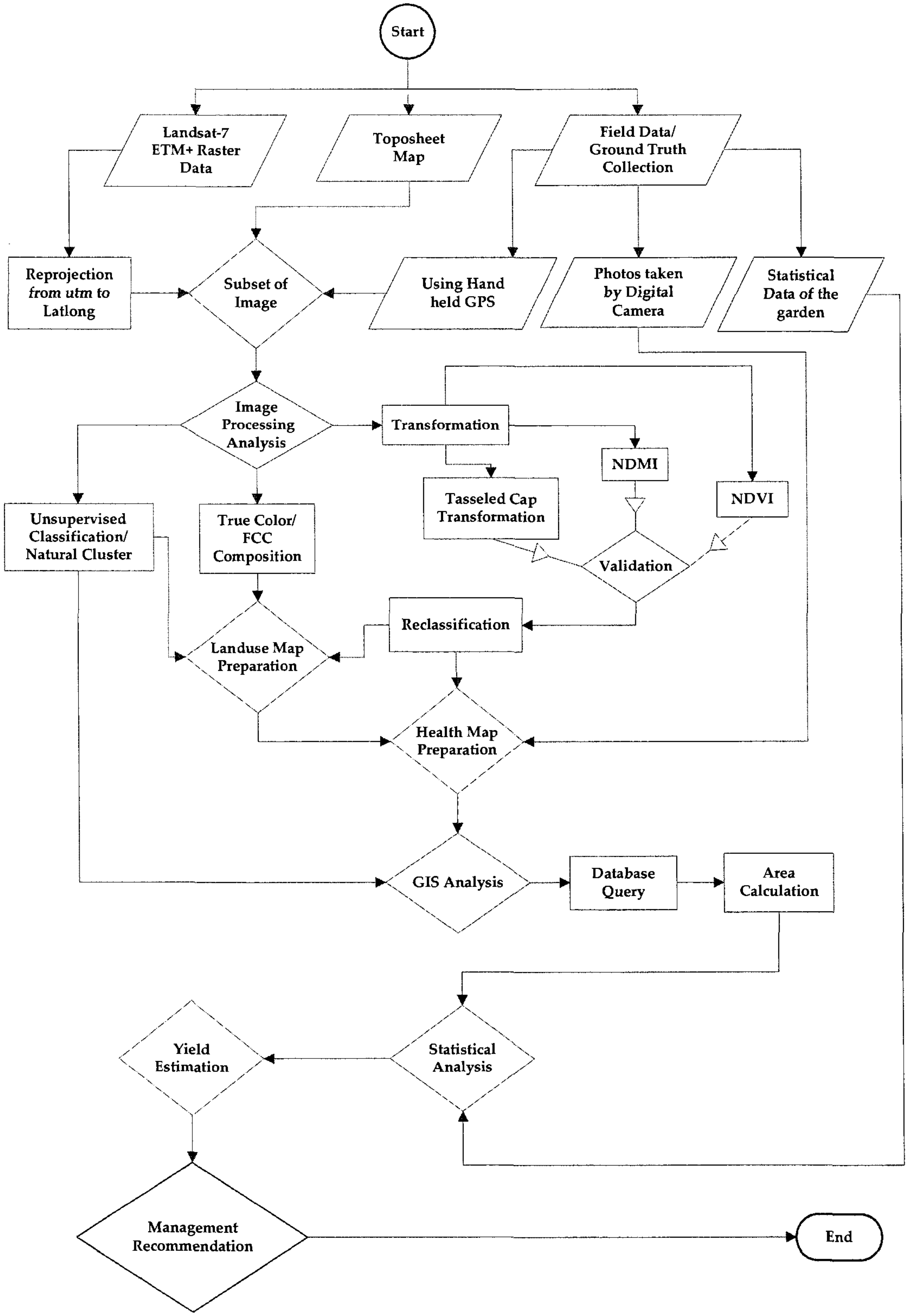


Figure 14. Methodology diagram

4.1. Band Composition and Visual Interpretation

Figure 15 portrays a part of the study are in six Landsat bands individually.

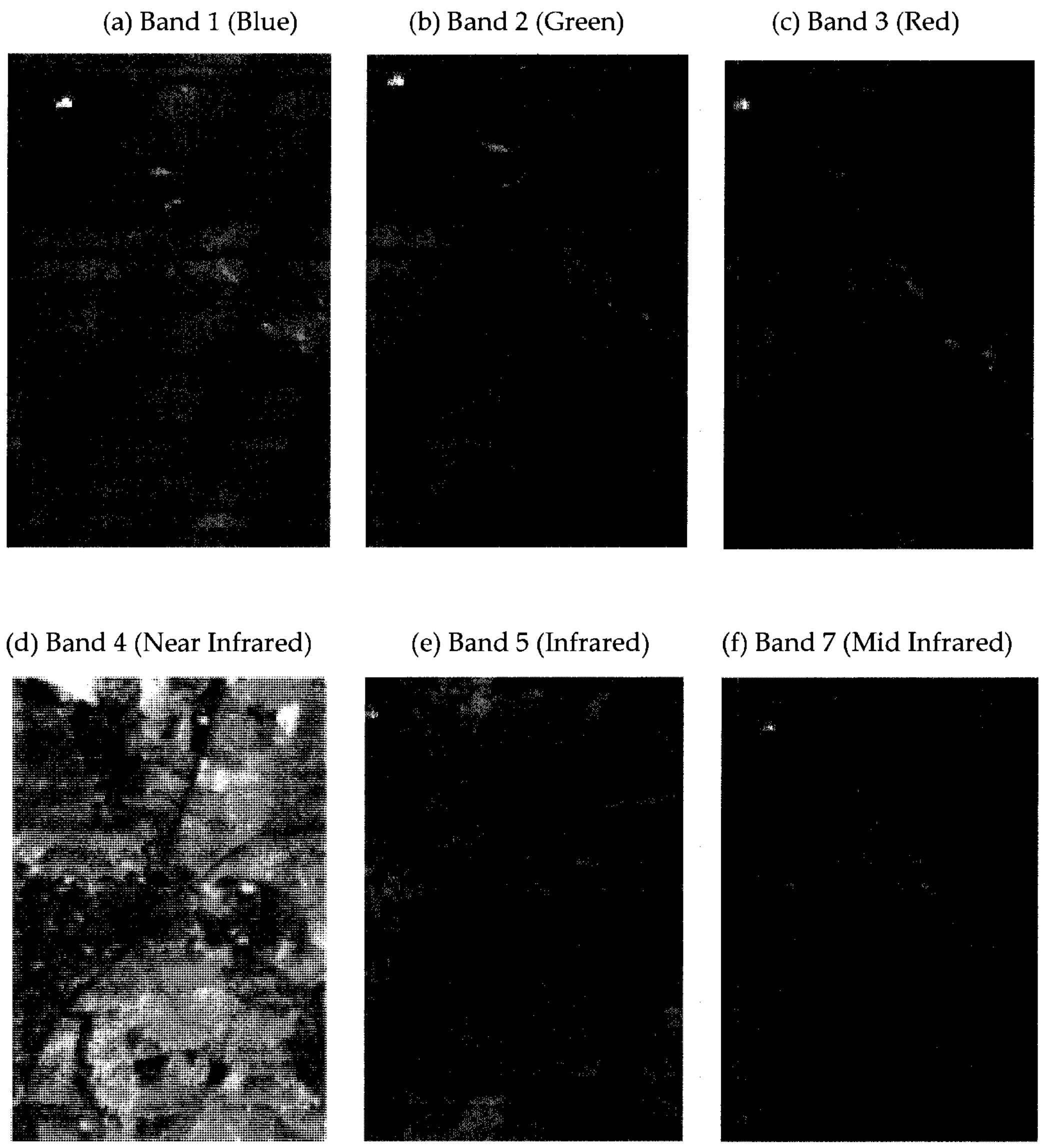


Figure 15. Raw images of the bands of Landsat-7 ETM+

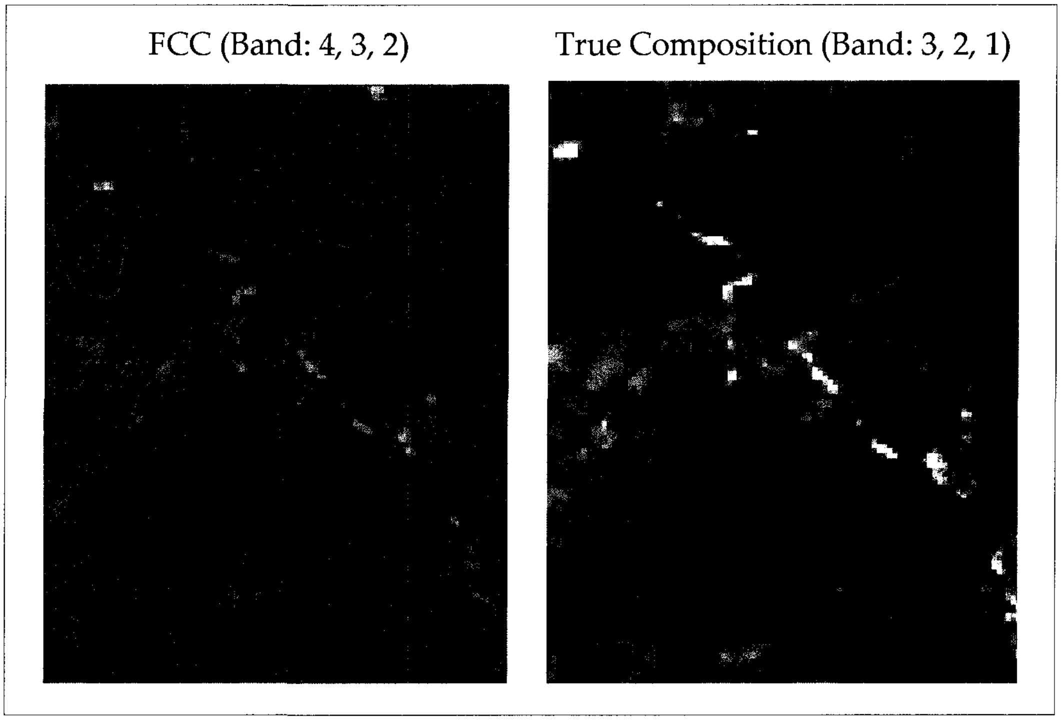


Figure 16. (a) Spectral reflectance of healthy, (b) moderately healthy and (c) stressed bush at a location of Hansqua tea garden, Terai Region, Darjeeling district.

The healthy, moderately healthy and unhealthy tea patches are visually interpreted. False color compositions (FCC) were generated using Landsat-7 ETM+ bands 4, 3, 2, and true color compositions were generated using the visible bands 3, 2, 1, respectively. The healthy and stressed tea patches can be distinctly separated from the other landuse classes in FCC composition image. Following is an interpretation of the FCC image:

i) **Tea Bush:** In the FCC image the tea patches have appeared in reddish color. The healthy tea bush appears in bright red color due to the higher reflectance while the moderately healthy tea bush appears in reddish brown color. The unhealthy or stressed bush appears in dark brown color.

ii) Forest/Other vegetation: Other vegetation like forest, crop lands and scrubs show up as pink to different shades of dark red.

iii) River: The River appears in dark blue with its unique linear and meandering shape that could be easily distinguished from the other land cover classes.

iv) River Bed/Bare Soil: River bed or bare soil appears in white and that could be identified along the river channel and sometime the soil with no vegetation also gives the same bright white reflectance.

v) Settlements: Settlements appear in light bluish color with coarse texture.

A reference map was prepared using the three interpreted tea health categories (Figure 17). Linear features and the regions of tea indicated by the topomap are included to provide context. Note that these regions do not entirely coincide; the interpreted image, as well as field examination, indicates the presence of tea cultivation that extend beyond the boundaries indicated in the topomap.

Landuse/ Landcover Map

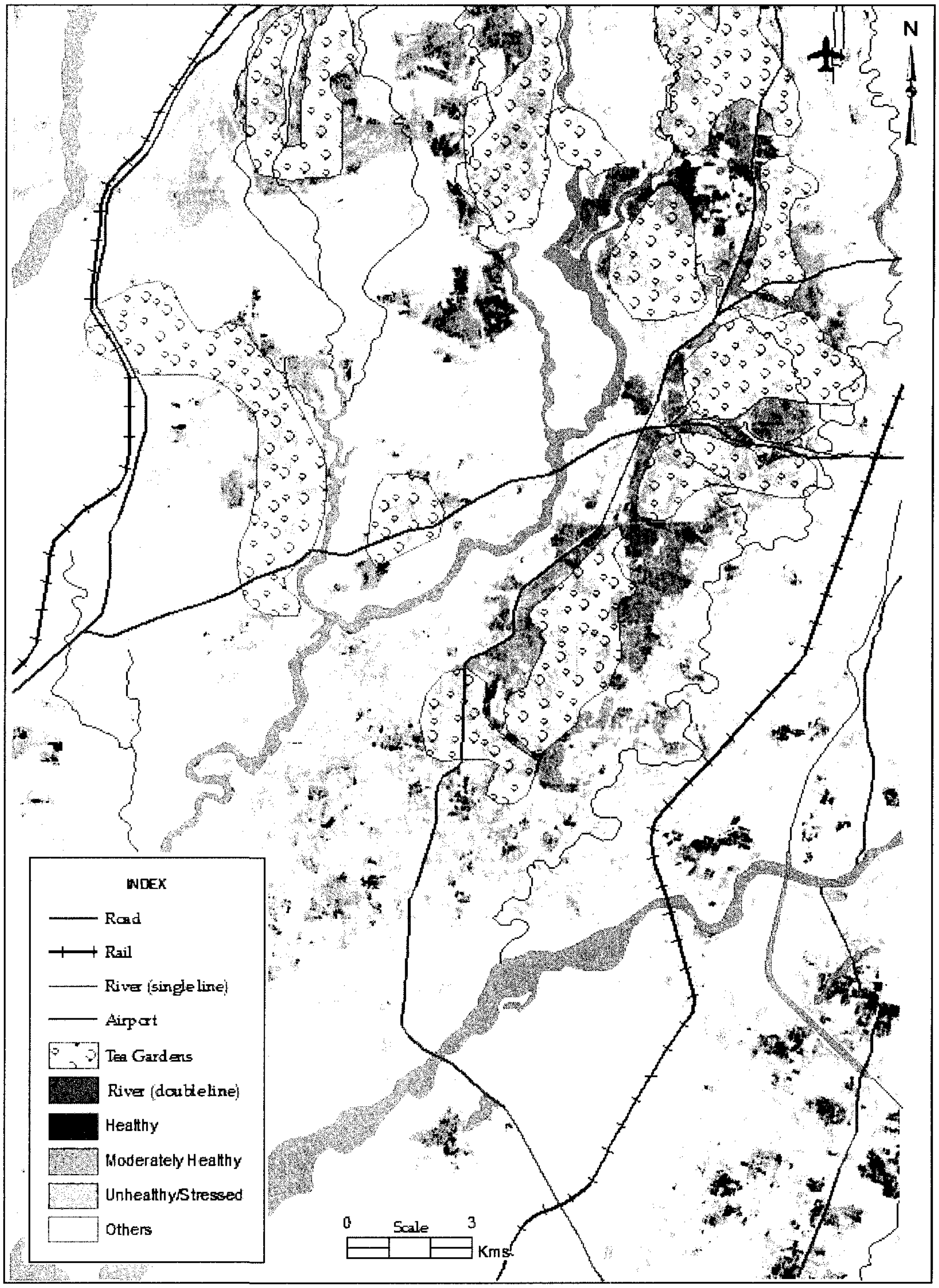


Figure 17. Land use/land cover map of study area; Hansqua tea garden and surrounding areas, Terai region, Darjeeling district.

4.2. Spectral Signature Analysis of Landsat-7 ETM+

Spectral signature analysis was performed for representing the reflectance variability between land cover classes and for evaluating spectral responses within land cover classes. The reflectance curves for all bands were generated for studying the pattern of spectral responses of each landuse/landcover classes. In Landsat imagery vegetation can be easily distinguished by its unique spectral signature.

The reflectance value of Landsat imagery ranging from 0-255 are represented by Digital Number (DN). The reflectance DN value of healthy, moderately healthy, and unhealthy or stressed, as well as seperability of tea's from other vegetation peaks in the near infrared (NIR) band are discussed here. The study of reflectance value for the different bands suggests that the NIR band could be the most useful for analyzing vegetation health. Any useful index should rely on this band. The low peak appearing in the red bad (band 3) and middle infrared (band 7) is mainly due to the absorption of chlorophyll. The river bed shows its peak in the red, TIR band, blue, green, MIR and NIR respectively. Table 2 portrays the representative spectral characteristics for selected classes, derived through careful interpretation. Figure 18 portrays this information in graphical form.

Table 2. Typical reflectance DN values ranging from (0-255) of different bands for the study area from images.

Band	Settlement	River	River Bed	Forest	Healthy Tea Bush	Moderately Healthy Tea Bush	Unhealthy Tea Bush
1	74	69	114	65	67	65	67
2	77	55	105	48	53	49	51
3	58	51	124	37	37	35	45
4	56	48	96	85	148	106	72
5	92	28	118	59	75	63	54
6.1	150	133	151	137	138	138	139
6.2	185	154	193	160	164	163	165
7	65	29	124	26	36	32	35

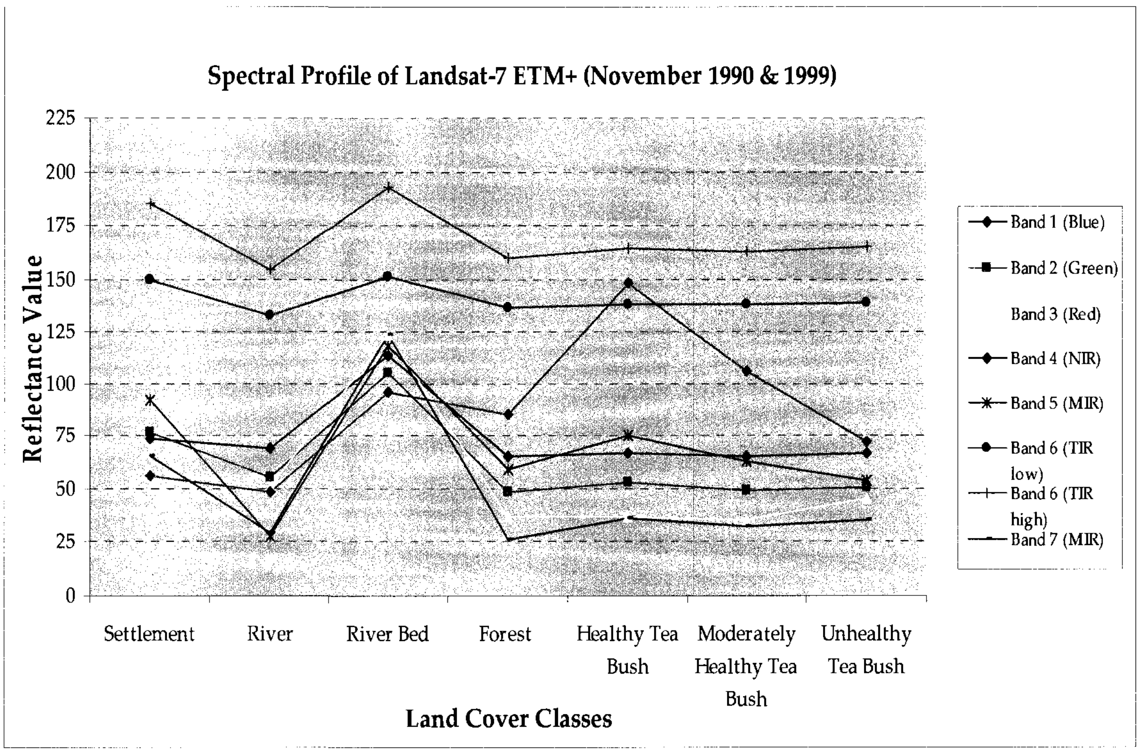


Figure 18. Graph showing the land use/land cover class seperability in Landsat-7 ETM+ November 1990 and 1999.

4.3. Image Processing Analysis

In the process of image analysis, unsupervised classification using the ISODATA algorithm was performed to determine data clustering, which could be used to derive spectral classes that exist in the image. The NDVI transformation was performed to derive a tea bush health index that could be used to classify healthy, moderately healthy and stressed tea bush areas. NDMI and Tasseled Cap image transformations were also attempted to determine the health of the bush along with NDVI index.

4.3.1. Unsupervised Classification

Unsupervised classification was used as an alternative method of deriving three tea health classes. The ISODATA algorithm was performed for both dates repeatedly with different numbers of clusters: 9, 15, 30 and 100. The classified images that were generated were compared with the NDVI and field study results (Figure 17). The best correspondence was obtained by setting the number of clusters to 15, and then assigning selected clusters to the three tea health classes, as shown in Figures 19 and 20 for a portion of the study area.

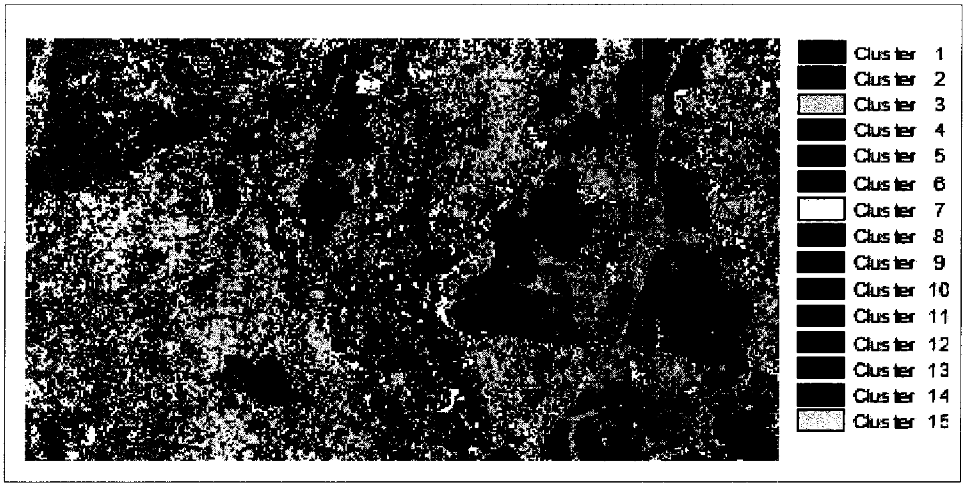


Figure 19. Unsupervised classification for 1990; Cluster 6: healthy tea bush, cluster 4: moderately healthy bush; cluster 5: stressed/unproductive tea bush.

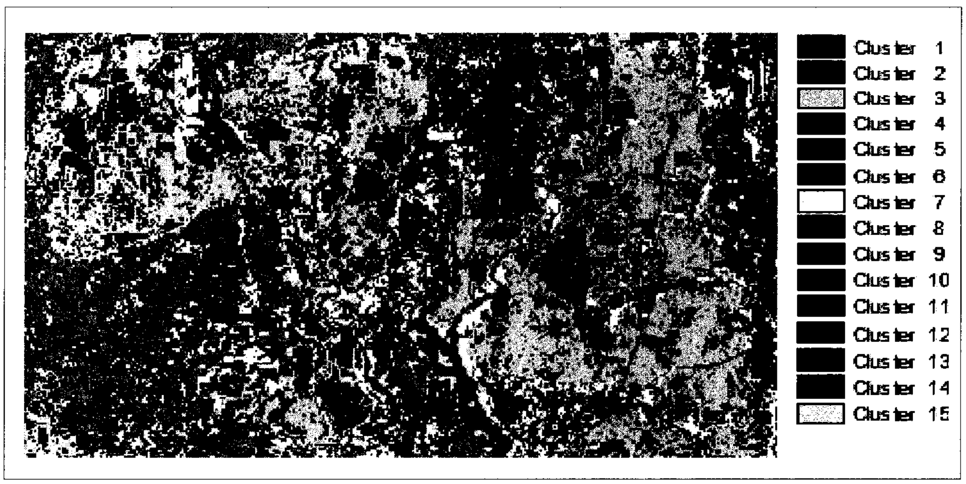


Figure 20. Unsupervised Classification for 1999; Cluster 5: healthy tea bush, cluster3: moderately health Tea Bush, cluster 4: stressed/unproductive tea bush.

4.3.2. Normalized Difference Vegetation Index (NDVI)

The NDVI vegetation index characterizes vegetation through a combination of the visible red and near infrared bands of any multispectral data.

Tea bush with healthy, moderately healthy and unproductive or stressed tea patches are recognized as higher to lower NDVI values respectively. Typical NDVI values for different categories of tea bush health are shown in Figure 21.

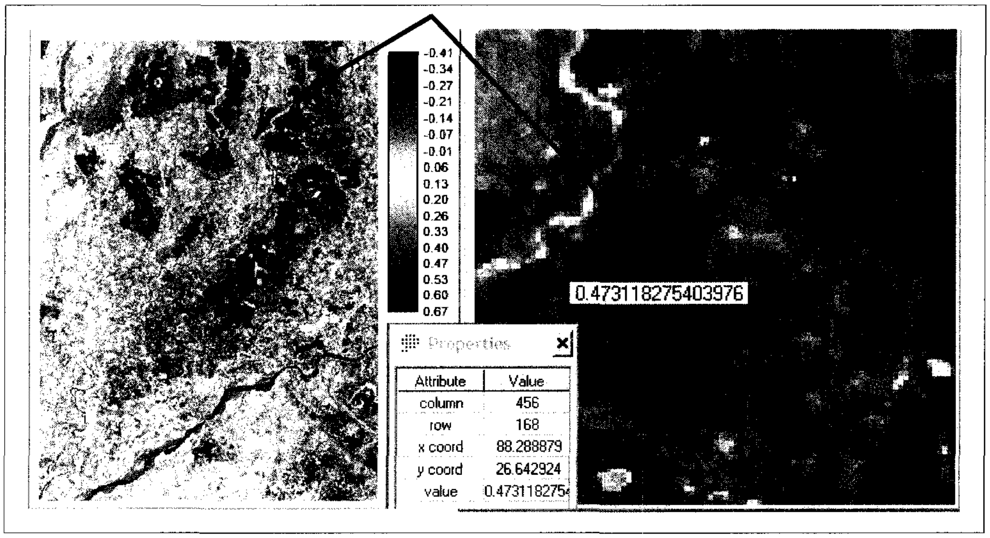


Figure 21 (a). Typical healthy tea bush NDVI

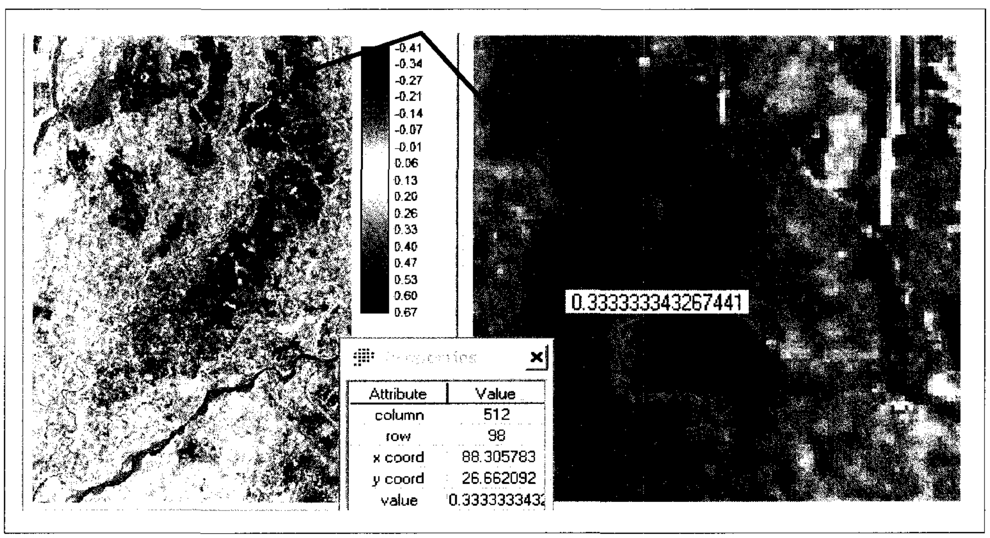


Figure 21 (b). Typical moderately healthy tea bush NDVI value

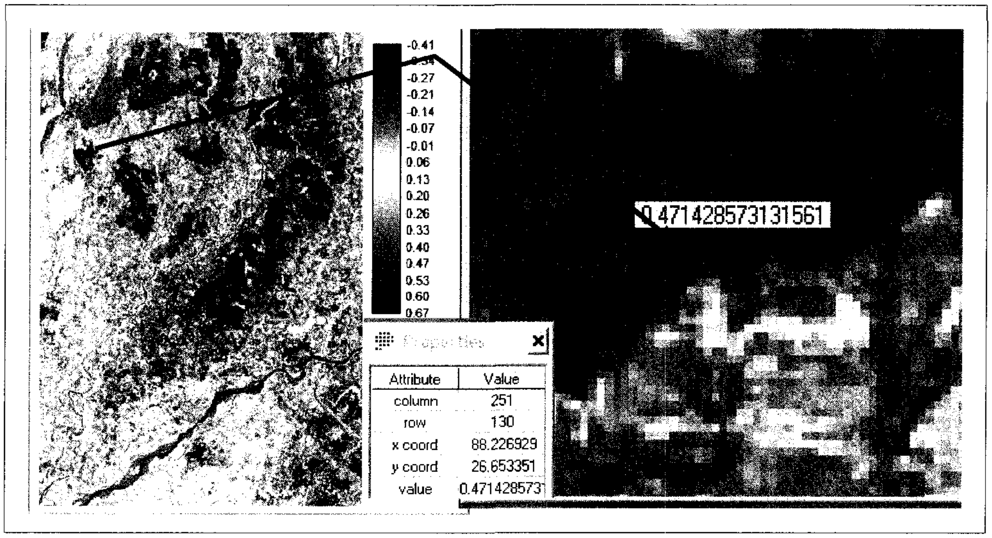


Figure 21 (c). Typical stressed tea bush NDVI value

4.3.3. Normalized Difference Moisture or Water Index (NDMI or NDWI)

NDWI image processing analysis was done to find the moisture index in the healthy, moderately healthy and stressed tea bush. The water index is (0.337) for the healthy tea canopy and very low water index for stressed tea bush (0.079). Negative NDWI index is found on concrete/manmade features. Typical NDWI index for different categories of tea bush health are shown in Figure 22.

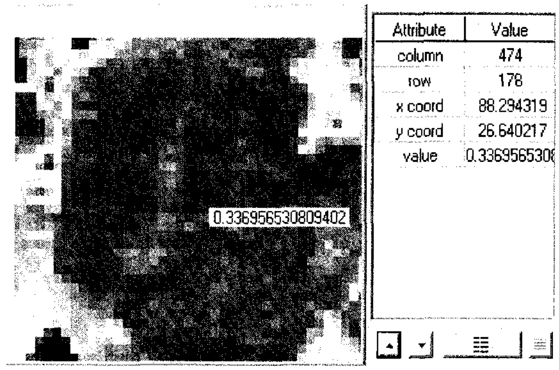


Figure 22 (a). Typical NDWI value for healthy tea bush

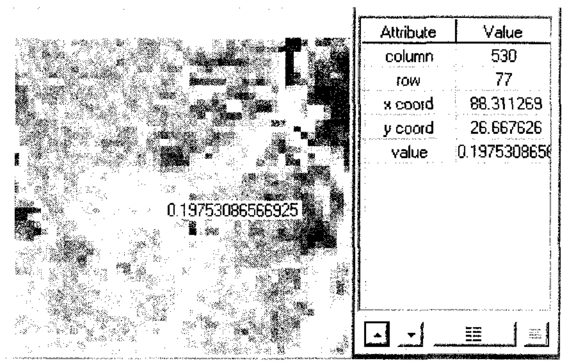


Figure 22 (b). Typical NDWI value for moderately healthy tea bush

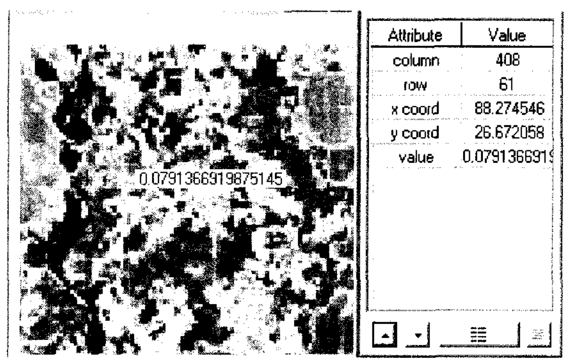


Figure 22 (c). Typical NDWI value for unhealthy/stressed tea bush

4.3.4. Tasseled Cap Transformation Index

The Tasseled Cap Transformation was performed in order to study its suitability in characterizing soil brightness, environmental wetness, and the health of tea leaf biomass for the study area.

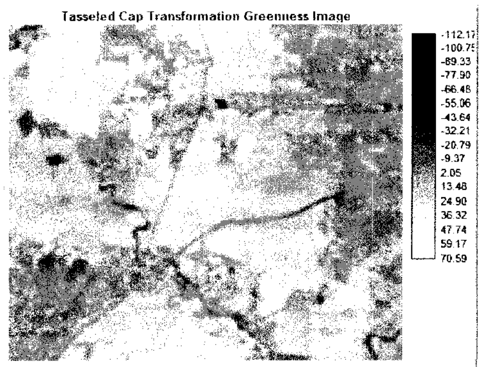


Figure 23 (a). Tasseled Cap Transformation Greenness image.

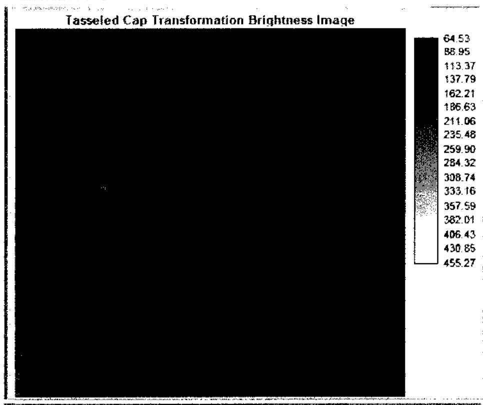


Figure 23 (b). Tasseled Cap Transformation Brightness image.

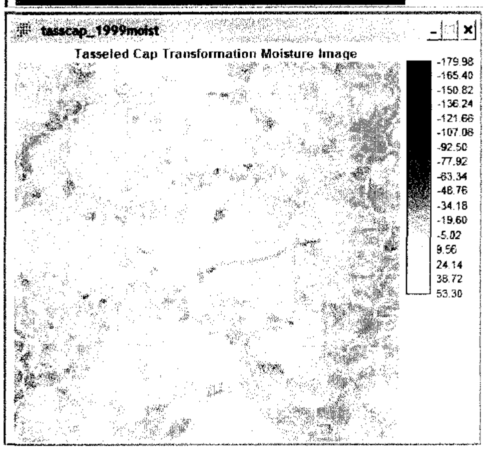
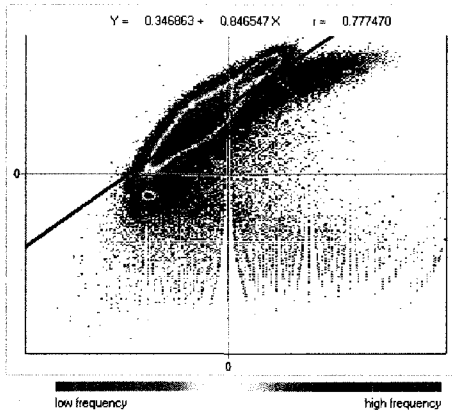


Figure 23 (c). Tasseled Cap Transformation Wetness image.

4.4. Regression Analysis

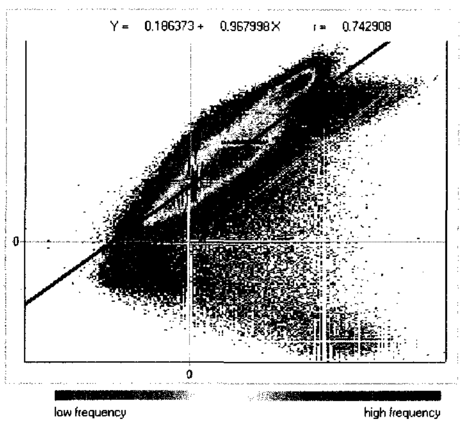
4.4.1. NDVI versus NDWI

Regression analysis for the transformed NDVI and NDWI image showed a *moderate linear correlation.* Figure 24 represents the linear regression between the images. The positive values for both NDVI and NDWI images constitute the main areas of analysis for this study. Higher NDVI values (on the Y axis) for the healthy tea bush canopy shows medium positive moisture content index values (X axis).




```
Regression Parameters:

X axis: ndmi_1990
Y axis: ndvi_clip_1990_hansq_rproj

Coeff. of Det.         =    60.45 %
Std. Dev. of X         =     0.150923
Std. Dev. of Y         =     0.164332
S.E. of Estimate       =     0.103352
Std. Error of Beta     =     0.000805
t Stat for r or Beta   =  1051.754783
t Stat for Beta <> 1   =  -190.650824
Sample Size (n)        = 723858
Apparent df            = 723856
```

Figure 24 (a). NDVI versus NDWI for 1990.

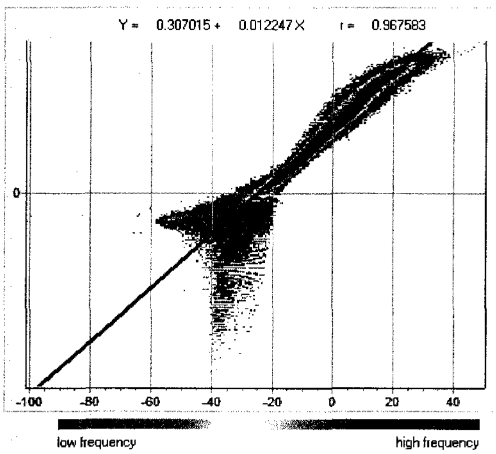



```
Regression Parameters:

X axis: ndmi_1999
Y axis: ndvi_clip_1999_hansq_rproj

Coeff. of Det.         =    55.19 %
Std. Dev. of X         =     0.122775
Std. Dev. of Y         =     0.159975
S.E. of Estimate       =     0.107086
Std. Error of Beta     =     0.001080
t Stat for r or Beta   =   896.240480
t Stat for Beta <> 1   =   -29.630042
Sample Size (n)        = 662145
Apparent df            = 662143
```

Figure 24 (b). NDVI versus NDWI for 1999.

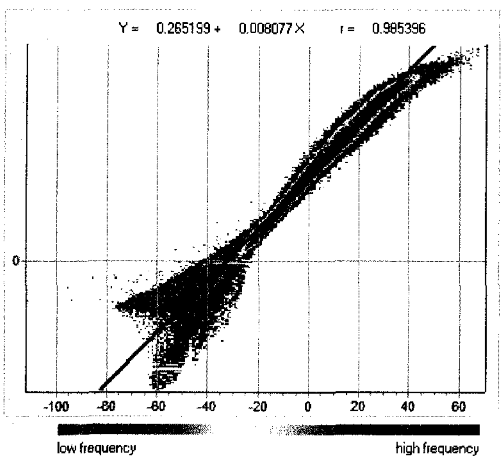
4.4.2. NDVI versus Tasseled Cap Greenness band

NDVI and Tasseled Cap bands were studied. Among them, only the NDVI and Tasseled Cap Greenness band shows strong *linear correlation* for both the 1999 and 1990 images (Figure 25). Regression results of NDVI with either Moisture or Brightness yielded very coarse relationship; those pairs are excluded from further investigation in this study.




```
Regression Parameters:

X axis: tassled_cap_1990green
Y axis: ndvi_clip_1990_hansq_rproj

Coeff. of Det.          =    93.62 %
Std. Dev. of X          =    12.983096
Std. Dev. of Y          =     0.164332
S.E. of Estimate        =     0.041502
Std. Error of Beta      =     0.000004
t Stat for r or Beta    =  3259.592724
t Stat for Beta <> 1    = -262892.747656
Sample Size (n)         = 723858
Apparent df             = 723856
```

Figure 25 (a). NDVI versus Tasseled Cap Greenness band for 1990.




```
Regression Parameters:

X axis: tasscap_1999green
Y axis: ndvi_clip_1999_hansq_rproj

Coeff. of Det.          =    97.10 %
Std. Dev. of X          =    19.518129
Std. Dev. of Y          =     0.169975
S.E. of Estimate        =     0.027240
Std. Error of Beta      =     0.000002
t Stat for r or Beta    =  4673.331660
t Stat for Beta <> 1    = -573969.494847
Sample Size (n)         = 652145
Apparent df             = 652143
```

Figure 25 (b). NDVI versus Tasseled Cap Greenness band for 1999.

4.4.3. NDWI versus Tasseled Cap Wetness band

The NDWI transformed image was compared with the Tasseled Cap Wetness band. Water bodies shows highest wetness values, and concrete structures and sand deposits show negative wetness values. This study examines values between these extremes, and attempts to explore the relationship of healthy tea bush and their level of water content. A dry climate is not suitable to the tea plants; neither is water logging or high air moisture content, which may cause diseases and favorable conditions for insect pests. Hence the moisture content determination and monitoring is very important for controlling the health of the plant. The relationship between NDWI and the Tasseled Cap Wetness band were checked and they have *moderate linear correlations* of 78.60% and 81.75% between them at the study area for 1990 and 1999, respectively (Figure 26). Determination of moisture using either of these indices could be very productive for the tea growers; they may help to identify the patches that are stressed and prompt growers take the effective measure.

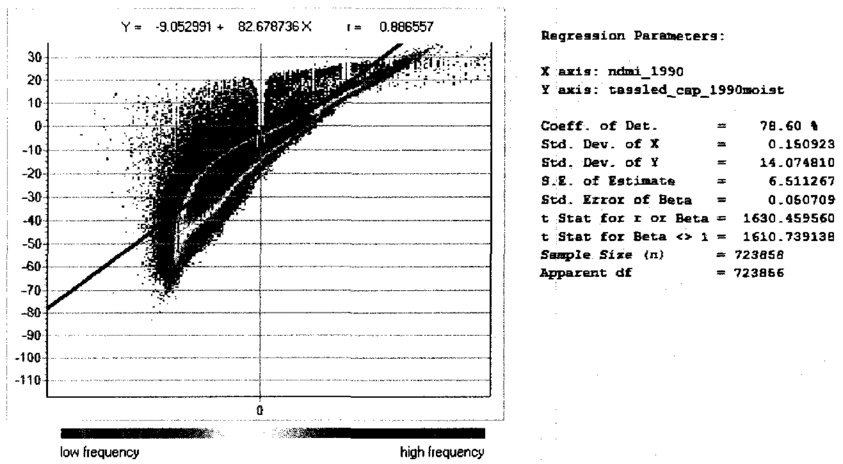


Figure 26 (a). NDWI versus Tasseled Cap Wetness band for 1990

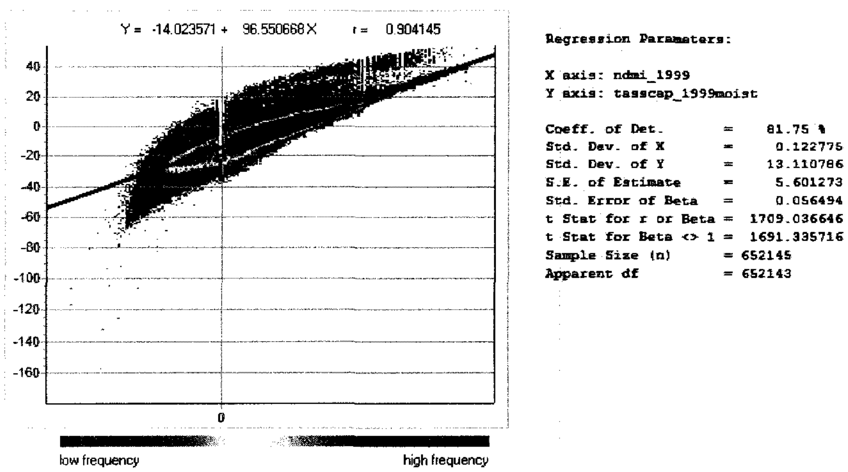


Figure 26 (b). NDWI versus Tasseled Cap Wetness band for 1999

4.5. GIS Analysis

4.5.1. NDVI–based Classification

The NDVI image was compared with landuse/landcover map as well as with RGB band composite image and FCC image for extracting the feature information (A. Ghosh et al., 2004). The NDVI image positive value represents tea leaf greenness.

NVDI results were the most reliable and practical basis for refining tea class into its three health subclasses (Dutta et al, 2005). Toward this end, a user-defined remapping of values was performed for the transformed NDVI images. The range of positive and negative NDVI values was studied thoroughly through comparison with ISODATA results and field observations, and a standard set of upper and lower threshold values was established for classification. These threshold values, and the classes to which they map, are as follows. The resulting images are portrayed in Figure 27.

Healthy Tea Bush (1):	all values from 1.00 to less than 0.55
Moderately Healthy Tea Bush (2):	all values from 0.55 to less than 0.05
Stressed/Unproductive Tea Bush (3):	all values from 0.05 to less than 0.42
Other Vegetation (4):	all values from 0.42 to less than 0.35
Bare Land with Some Crop Land (5):	all values from 0.35 to less than 0.01

Open ground with moist (6): all values from 0.01 to less than 0.05

Sand Deposition/Concrete

/ Manmade Feature (7): all values from 0.05 to less than -0.05

River Bed (8): all values from -0.05 to less than -0.25

River (9): all values from -0.25 to less than -1.00

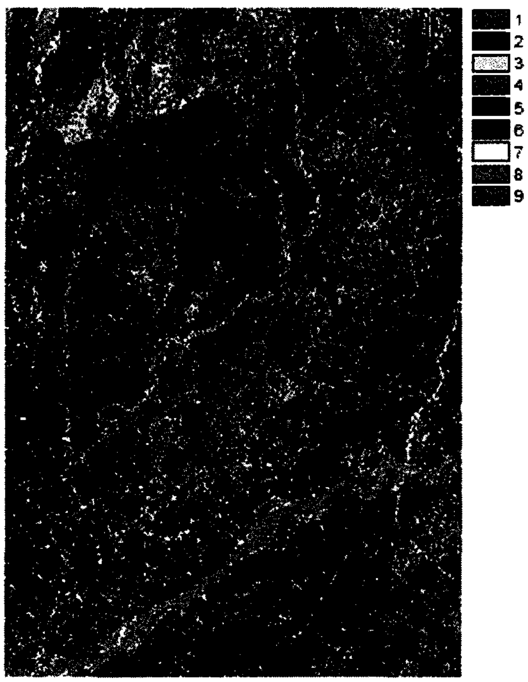


Figure 27 (a). Classified image for 1990.

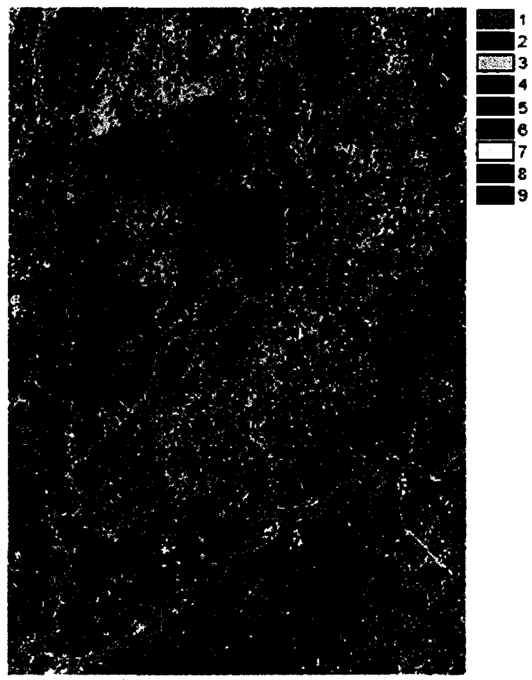
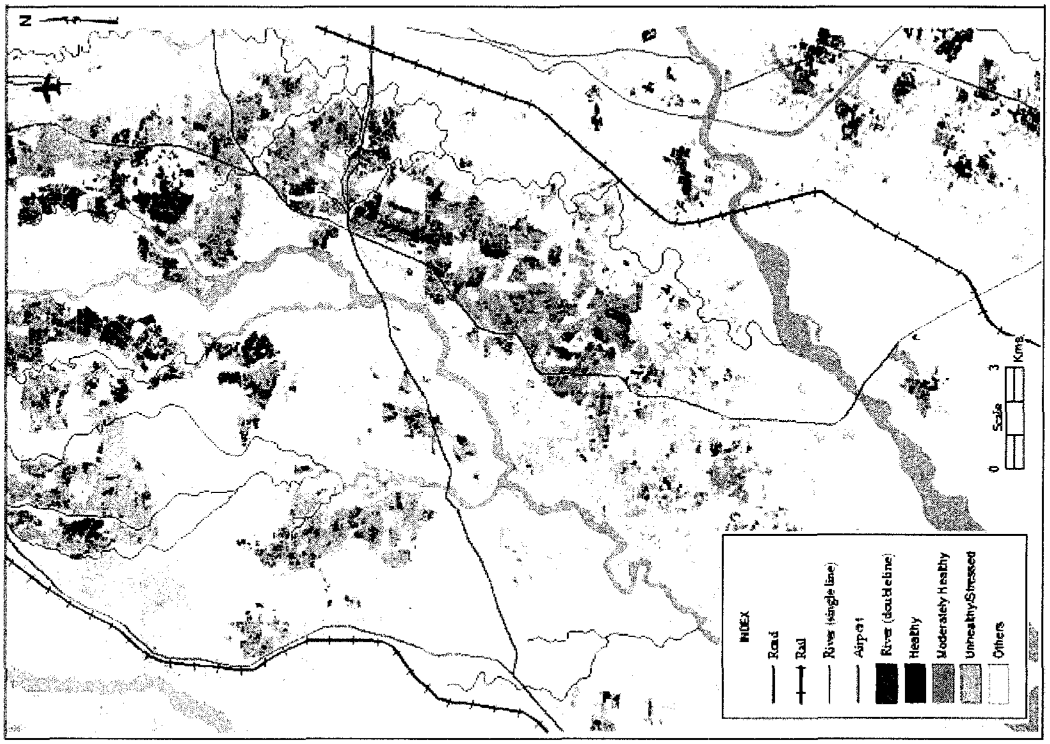


Figure 27 (b). Classified image for 1999.

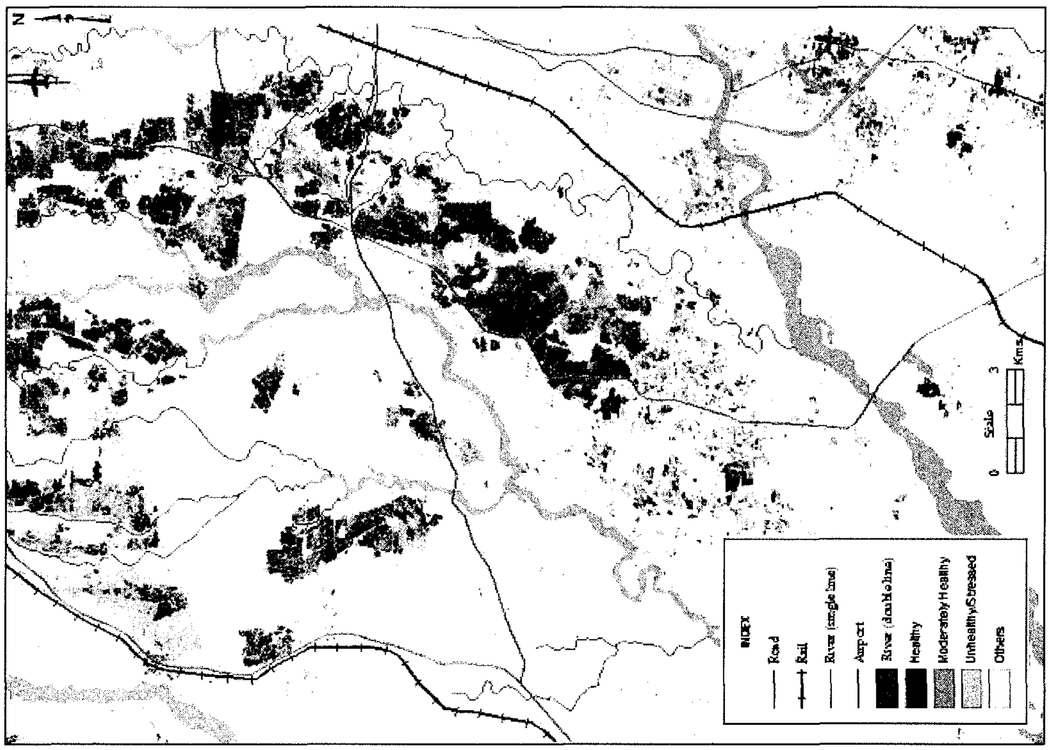
5.0. TEA BUSH HEALTH MAPPING

After exploratory analysis and comparison of results, it was decided that the NDVI transformation of Landsat-7 ETM+ image data formed an adequate basis of analysis the mapping of tea bush health. The user defined classification represents about the health of the tea bush canopy.

The classified data represented in Figure 27 were brought into the ArcView 9.2 environment and overlaid on the previously prepared base map. The resulting map represents tea health, and is meant to identify locations which need immediate action. The resulting health maps for 1990 and 1999 are shown in Figure 28. Two trends are easily discerned. First, the tea bush health has declined from 1990 to 1999. Secondly, the areas under cultivation have increased over the same period. These two trends are analyzed in greater detail in the following sections.



Tea Health Map for 1999



Tea Health Map for 1990

Figure 28. Tea Health map for 1990 and 1999 for the Study area: Hansqua tea garden and surrounding area, based on Landsat image during November.

6.0. QUANTITATIVE ANALYSIS

This section introduces data regarding areas under cultivation, and the relative proportions of tea health categories, from the Tea Board of India. Quantitative comparisons of these data with the results of both the unsupervised ISODATA classifications and the NDVI-based classification were performed for years 1990 and 1999.

6.1. Results from Cluster/Unsupervised Classification

Results of the calculation or areas under cultivation using the unsupervised classification method are portrayed in Figure 29 and Table 3 for year 1990 and 1999. Tea yield depends on health of the shoots of tea plant. For the unsupervised classification, the healthy and moderately healthy are considered to be productive, and stressed tea bush are considered to be unproductive or not have any contribution towards the gross annual yield.

According to Tea board data, the tea cultivation area under cultivation in the Terai region (which is dominated by the study area but includes some small regions outside as well), has increased from 1990 to 1999 by 50.75%. The areal analysis of the unsupervised classification results shows a 32.40% in area under cultivation within the study area.

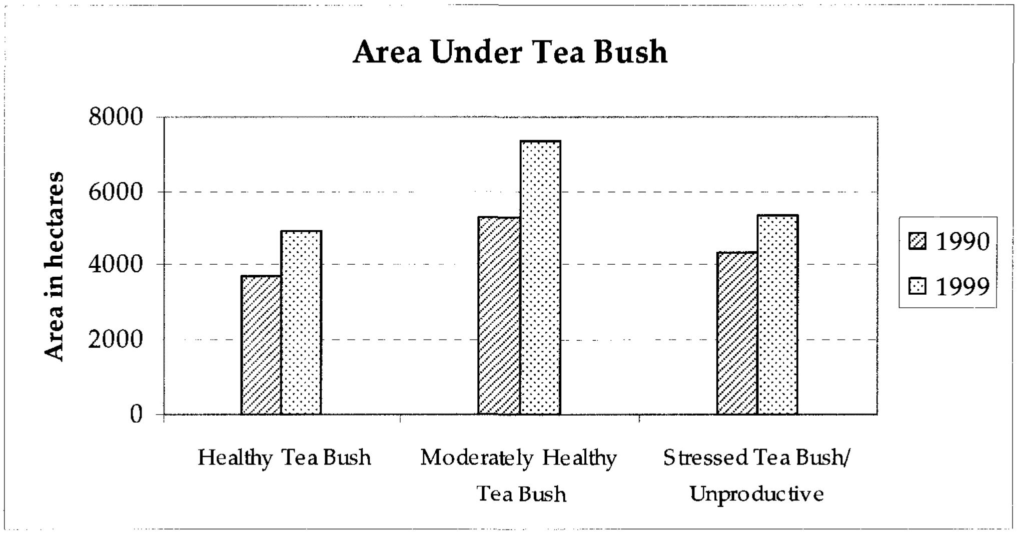


Figure 29. Area under different categories of tea health from unsupervised classification results, 1990 and 1999.

Table 3. Area under different categories of tea health from unsupervised classification results, 1990 and 1999.

Tea Bush Health	**Total Area 1990 (in hectares)**	**Total Area 1999 (in hectares)**
Healthy Tea Bush	3704.90	4921.97
Moderately Healthy Tea Bush	5275.94	7356.16
Stressed/Unproductive Tea Bush	4311.41	5321.66
Total Area	13292.25	17599.79

Table 4. Total calculated area from unsupervised classification method, and total area recorded by Tea Board for 1990 and 1999.

	Tea Garden Areas (in hectares)	
	1990	1999
Image Analyzed Areas	13292.25	17599.79
From Tea Board Data	13345	20118

Figures 30 and 31 shows area percentage for different categories of tea health computed from the unsupervised classification. In 1990 the healthy, moderately healthy and stressed tea bush were 28%, 40% and 32% where as in 1999 were 28%, 42% and 30% of the total area respectively. The total area under cultivation over the period of 1990 to 1999 increased, as well as the percentage of moderately healthy and stressed or unproductive area. The increase in total area compares favorably with data provided by the Tea Board of India (Table 4). Healthy area also increased with the increase of total tea garden area but the ratio for healthy area remains at the same value of 28%. The results were further analyzed by comparison with statistical data of Tea Board of India (Figure 36 and 37), and are discussed in the next section.

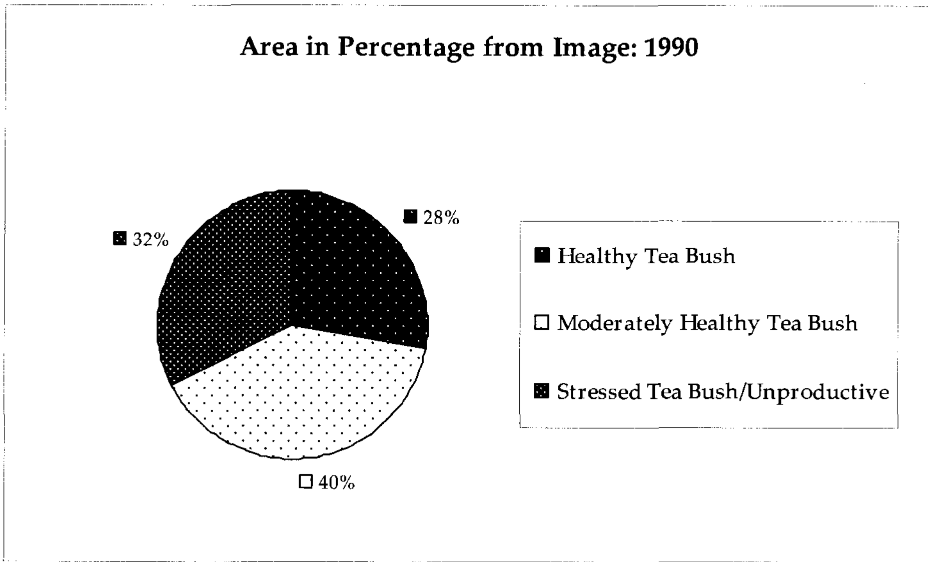


Figure 30. The percentage of healthy, moderately healthy and stressed tea bush area computed from unsupervised classified 1990 data.

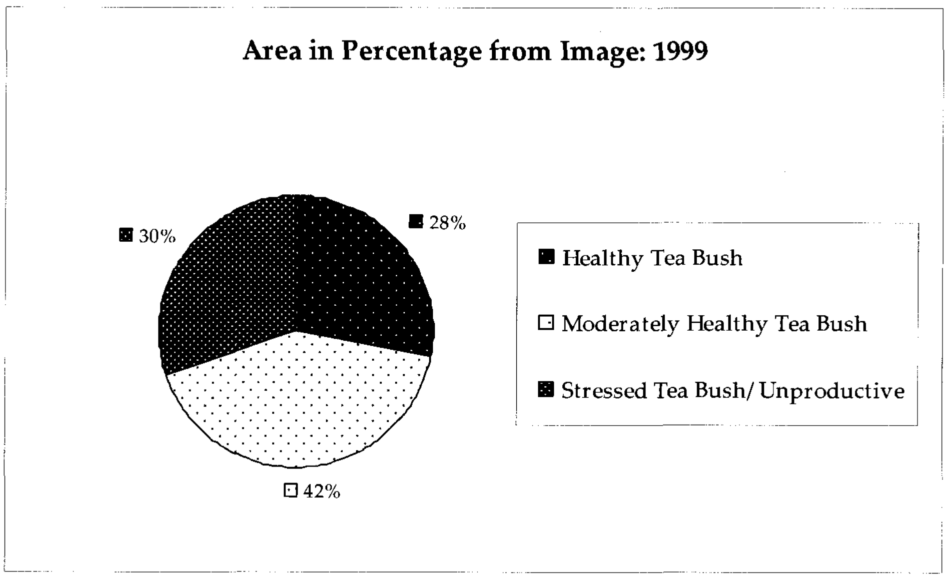


Figure 31. The percentage of healthy, moderately healthy and stressed tea bush area computed from unsupervised classified 1999 data.

6.2. Results from NDVI-based classification

NDVI Image has been reclassified and tea bush are categorized as healthy, moderately healthy and stressed tea bush on the bases of NDVI value. Higher NDVI values represent healthier tea bush than the lower NDVI value.

GIS analysis was done for reclassified image and area was calculated for healthy, moderate healthy and stressed tea bush patches in hectares are shown in Figure 32 for year 1990 and Figure 33 for year 1999 and Table 5 represent the total area.

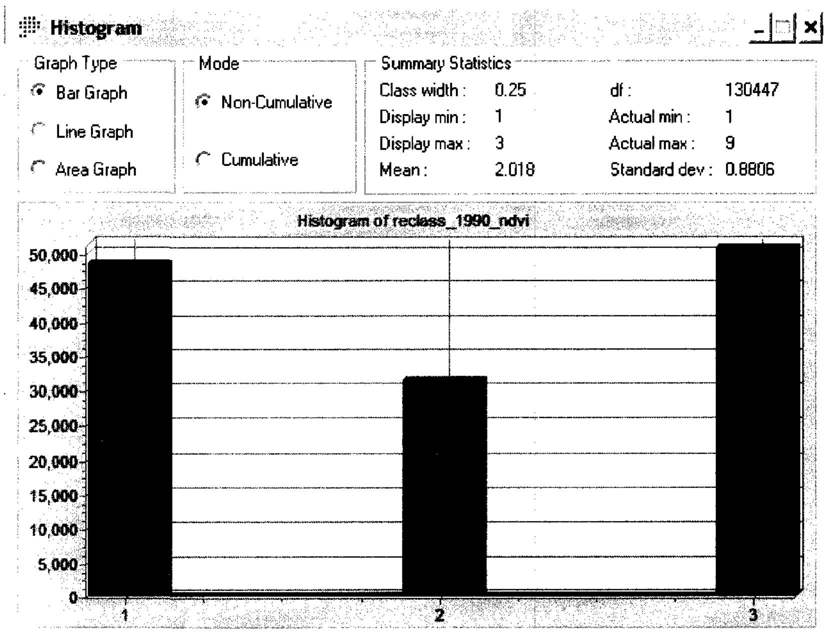


Figure 32. Histogram showing the pixel frequency of NDVI based classified data for 1990. (1) shows the healthy bush pixel, (2) shows the moderately healthy tea bush and (3) shows stressed pixel frequency.

A histogram has also been created where the pixels of same spectral value have been represented in a bar graph. The total number of pixels of the same spectral value has been calculated and converted to the area in hectares.

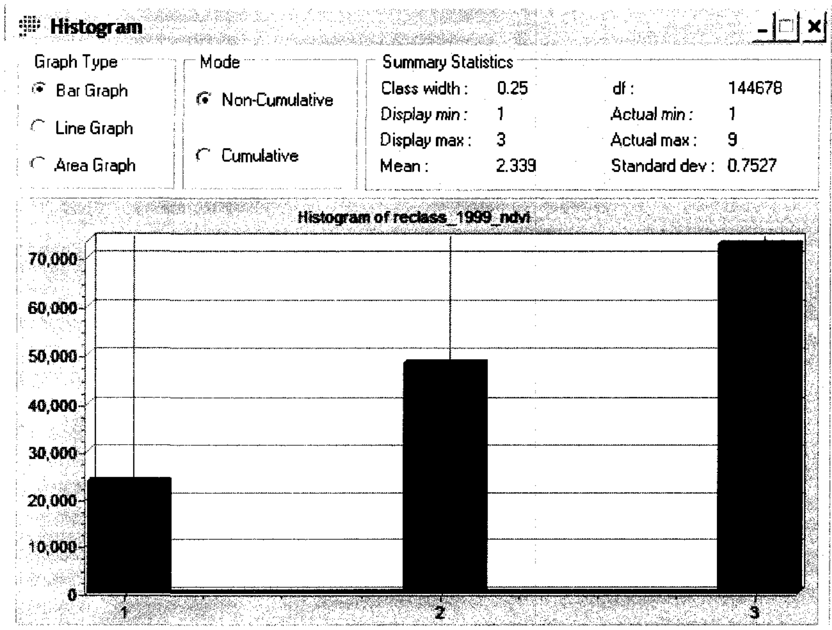


Figure 33. Histogram showing the pixel frequency of NDVI based classified data for 1999. (1) shows the healthy bush pixel, (2) shows the moderately healthy tea bush and (3) shows stressed pixel frequency.

Table 5. Area under different categories of tea health from NDVI-based classification results, 1990.

Tea Bush	Total Area in hectares: 1990	Total Area in hectares: 1999
Healthy	3978.06	2154.59
Moderately Healthy	2570.06	4403.72
Stressed/ Unproductive	4171.5	6623.23
Total Area in Hectares	10719.62	13181.54

The ratio of healthy, moderately healthy and stressed tea bush patches has compared and the ratio for tea bush health category for the study area shows exactly same result by using GIS analysis and histogram analysis.

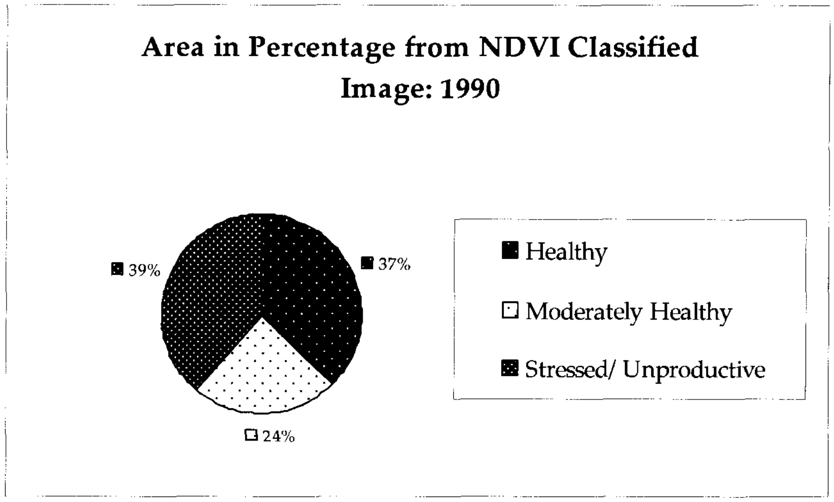


Figure 34. Tea bush health category in percentage extracted from NDVI-based classification data, 1990.

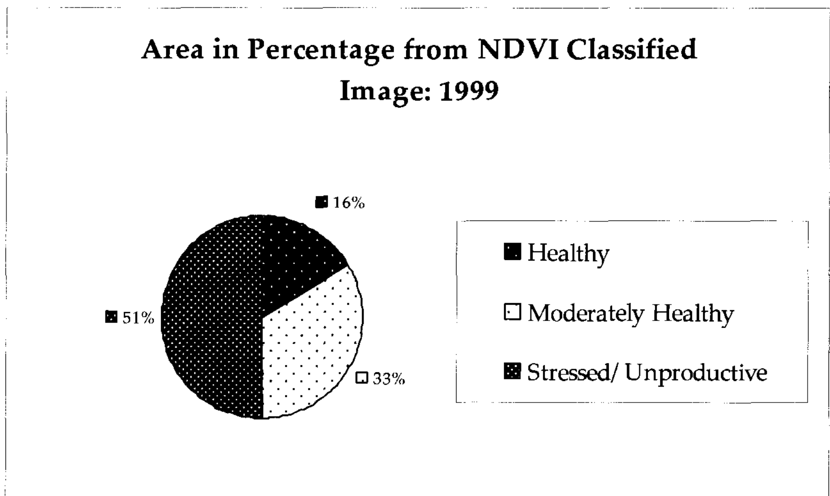


Figure 35. Tea bush health category in percentage extracted from NDVI-based classification data, 1999.

The cultivation areas containing different age groups were also analyzed for this study. The tea plant becomes mature in three to six years and is considered being productive. In six years it branches out and imageries are observed to have a healthy spectral reflectance. Spectral reflectance value of tea bush under five years will be similar to be stressed tea bush spectral value. From the year 1989 to 1995 the cultivation area was stagnant. The total production was also stagnant (Data source, Tea board of India). From 1996 the production has started increasing with the increase in cultivation area. By interviewing the managers of the garden, they also testified to the lower production period for those years. To increase the quality and production they started uprooting the aged or unproductive plants and replanting new tea plants.

The statistical data shows the ratio of tea bush below five years in 1990 was 9% and the number of new plants had increased to 30% in 1999. Due to uprooting of old tea bush, the ratio of tea plants of 41 years to over 50 years became less and it was 32% in 1999 and 49% in 1990.

The reclassification result from Landsat image of 1990 and 1999 also shows the total area for healthy spectral reflectance was more in comparison to 1999 reclassified image. The stressed tea patches area was more in 1999 than 1990 because the lower NDVI value from stressed tea bush as well as from the plants below five years. The moderately healthy tea patches have also increased in 1999 and the ratio was 33% and in 1990 it was 24% of the total area.

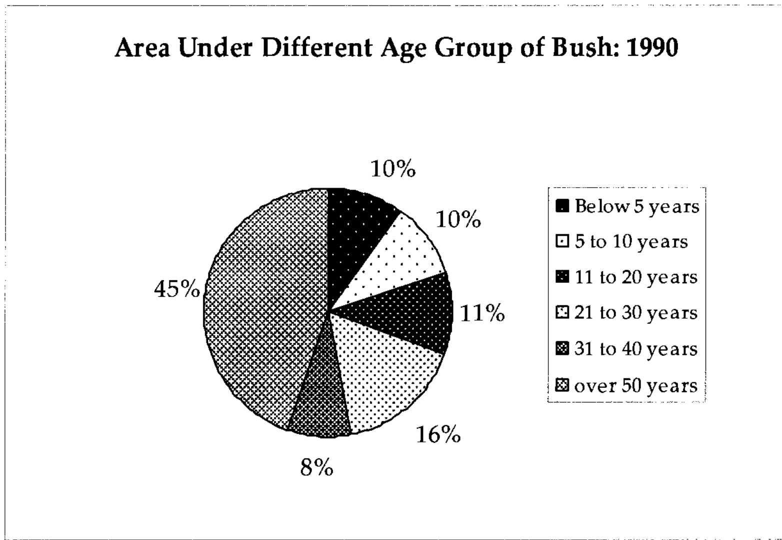


Figure 36. Area percentage of different age groups of tea plants in 1990.
Source: Tea Board of India.

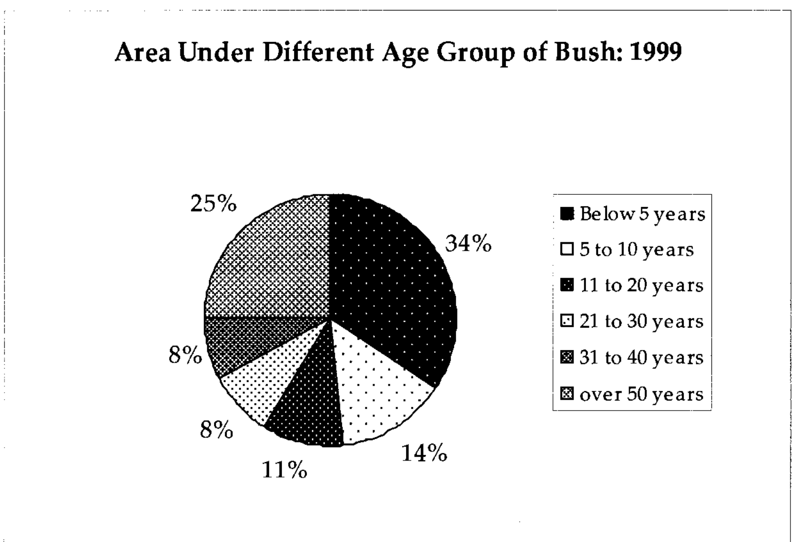


Figure 37. Area percentage of different age groups of tea plants in 1999.
Source: Tea Board of India.

7.0. TEA YIELD ESTIMATION

The tea yield increased in the Terai region, and total production doubled in 1999 as compared to 1990. The NDVI reclassification has been created to calculate the percentage of healthy and stressed tea bush area in the image. There is a direct correlation between the healthy tea bush and the quality of tea. The health of the tea bush is analyzed and validated with statistical record of production and sale from auction market. The percentage of healthy bush was 37% in 1990. In 1999 the percentage of healthy bush was 16% which was almost half the area under healthy tea bush in compared to 1990. Consecutively the trend of quantity sold was studied for Kolkata (city market) and Siliguri (local market) auction market for 1990 and 1999 are studied. The state level and national level production recorded by Tea Board India also indicates that the total production increased in 1999. The production trend from 1989 to 2001 is represented in Figure 41 according to Kolkata and Siliguri auction market. Production of Terai tea is estimated by nearby Siliguri and Kolkata auction market trends. With the hike in labor costs and other necessary production costs the sale price for per kg also increased in 1999 over 1990 levels. The average sale price for Siliguri and Kolkata was below average until 1996, and it crossed the average price in 1997 and reached highest sale price in 1998 (74.81 Rs/kg for

Siliguri auction and Kolkata 95.60 Rs/kg). Prices started falling in 1999 to 72.59Rs/kg and 75.59 Rs/kg for Siliguri and Kolkata. The sale price for Kolkata and Siliguri auction market is shown in Figure 42.

The quantity exported at the national level for the month of November also experienced a downward trend from 27819 thousand Kgs in 1990 to 19851 thousand Kgs in 1999. Quality is a major factor for export and which is very important for the tea industry.

The data were analyzed for 1990 and 1999 and it shows that the absolute area increased as well as total production in absolute terms is also increased. The health of the tea bush in absolute terms decreased and the quality of tea production also decreased and which affects the unit price Rs/kg. The NDVI reclassification analysis shows the deterioration of tea plant health. Therefore this method could be very useful for health identification as well as estimation of profit and determining auction market trends.

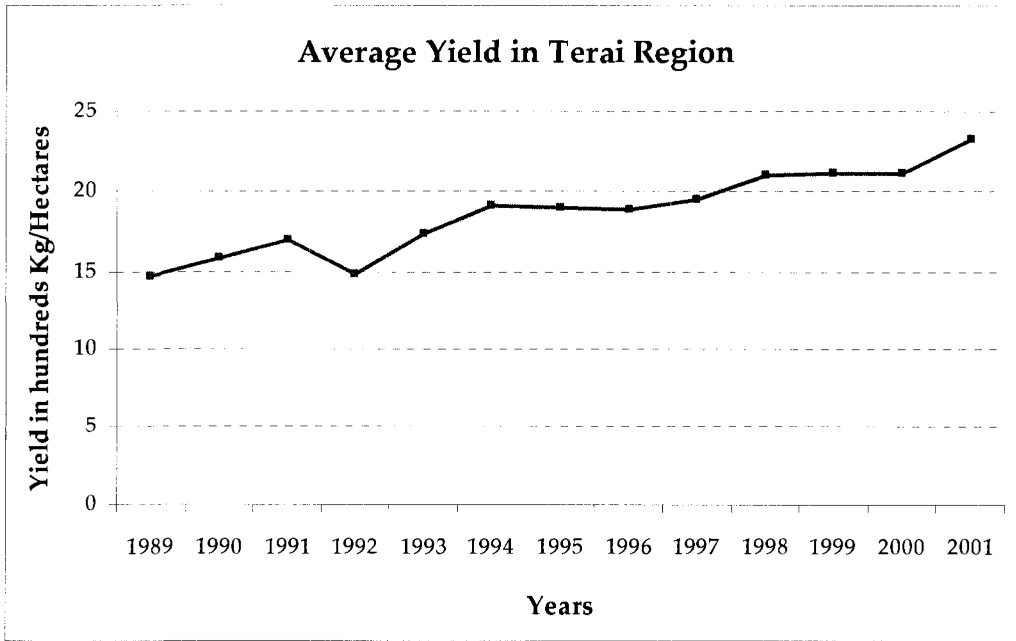
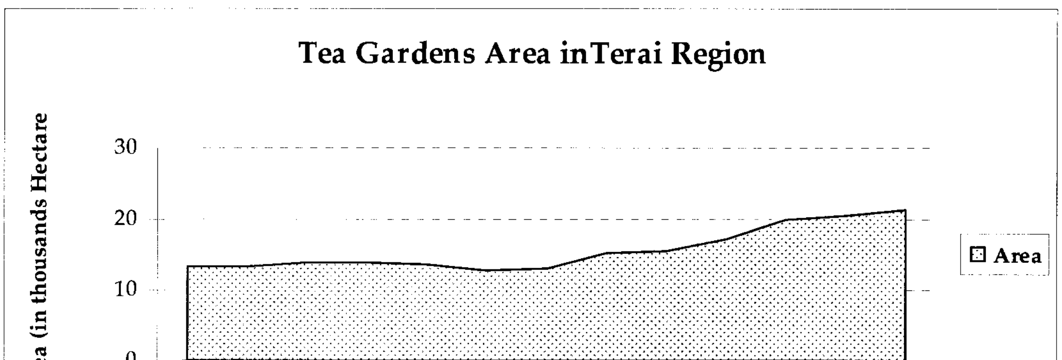


Figure 38. Trend of average yield in kg/ hectare annually in Terai region from 1989 to 2001. Source: Tea Board of India.



YEARS	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Area	13325	13345	13783	13790	13655	12908	13083	15351	15618	17315	20118	20548	21258

Figure 39. Area under tea cultivation from 1989 to 2001.
Source: Tea Board of India.

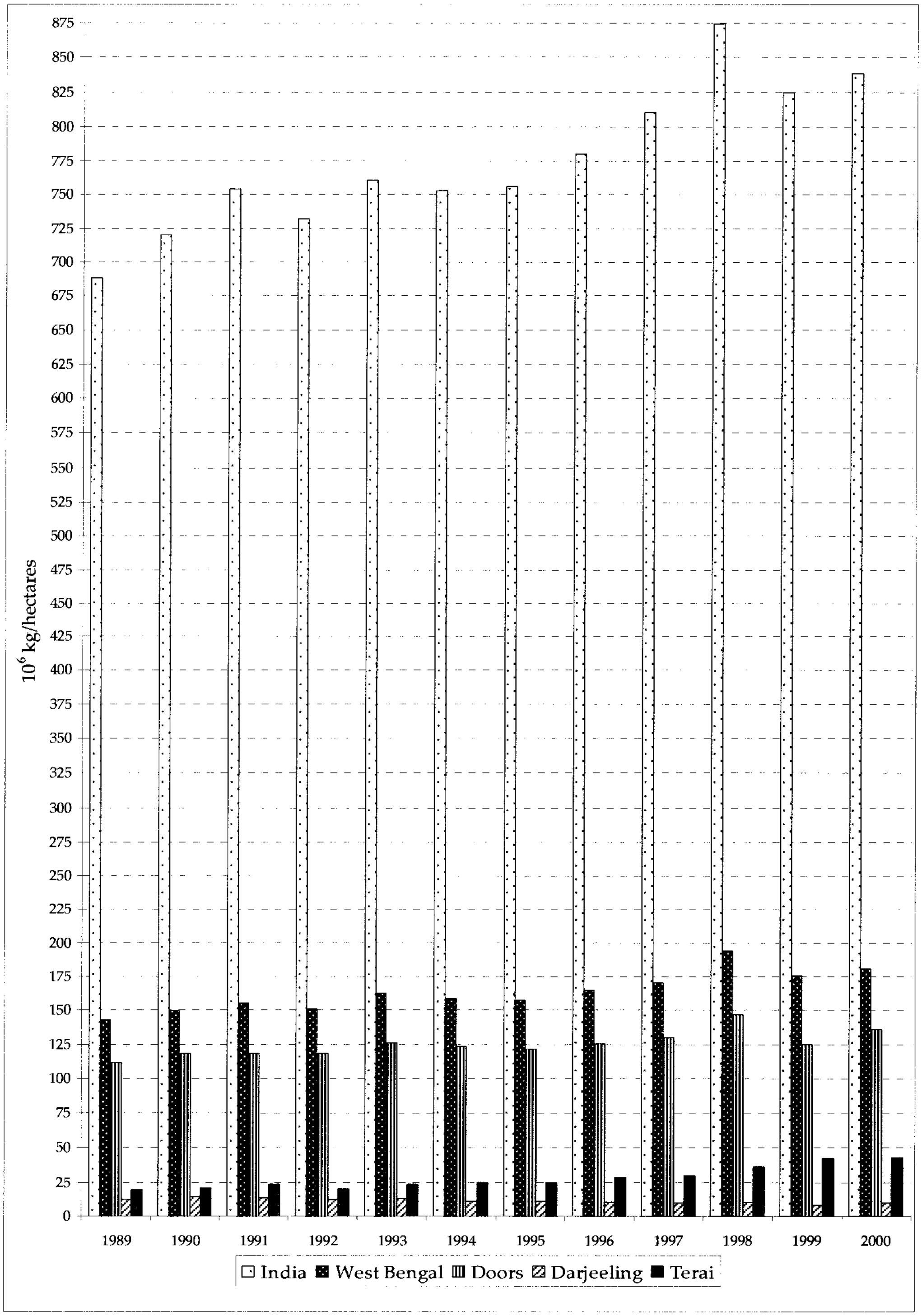
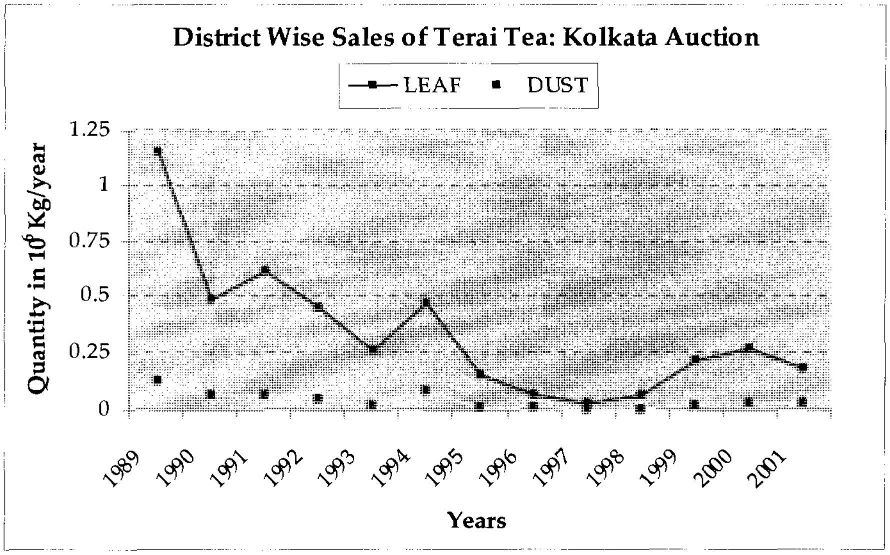
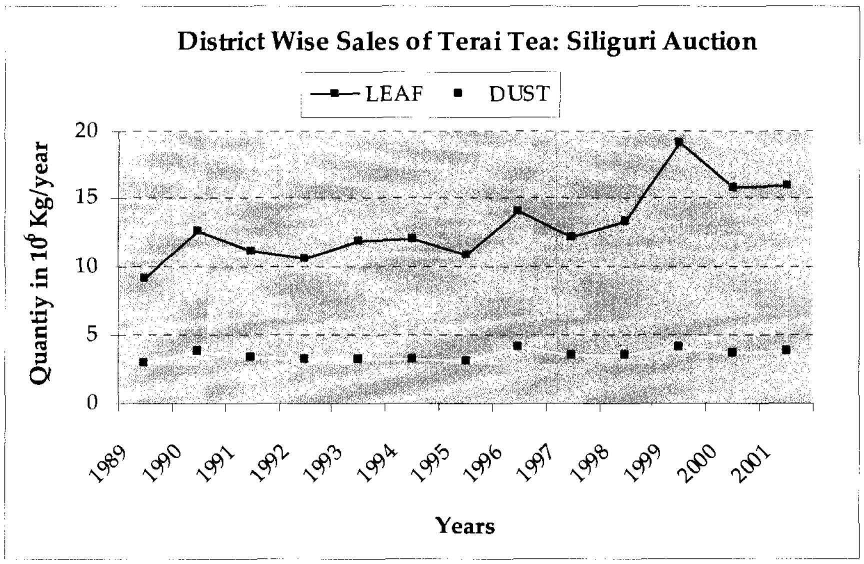


Figure 40. The trend of tea production in 10^6 kg/hectare at the national level (India), state level (West Bengal) and local level (Door, Darjeeling and Terai). Source: Tea Board of India.

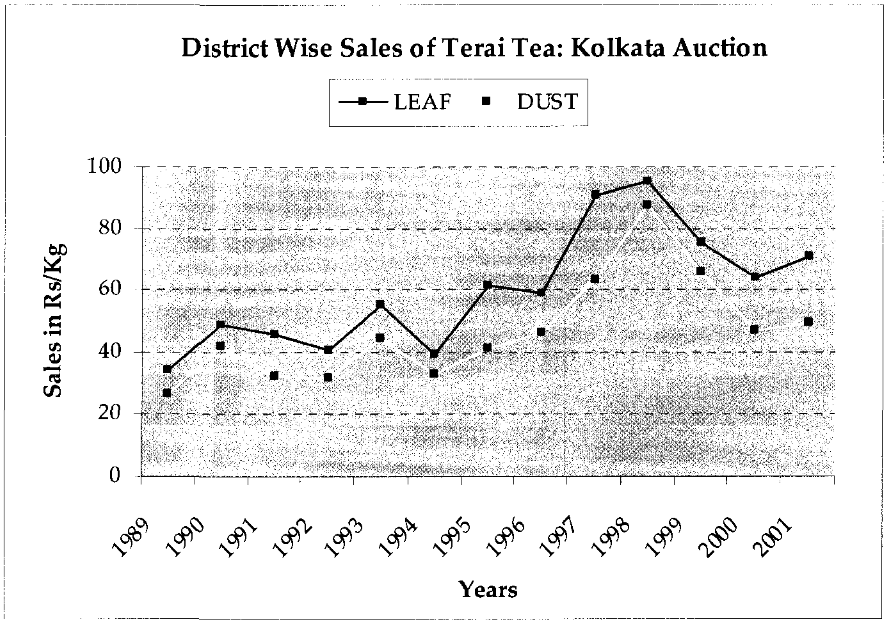


(a)

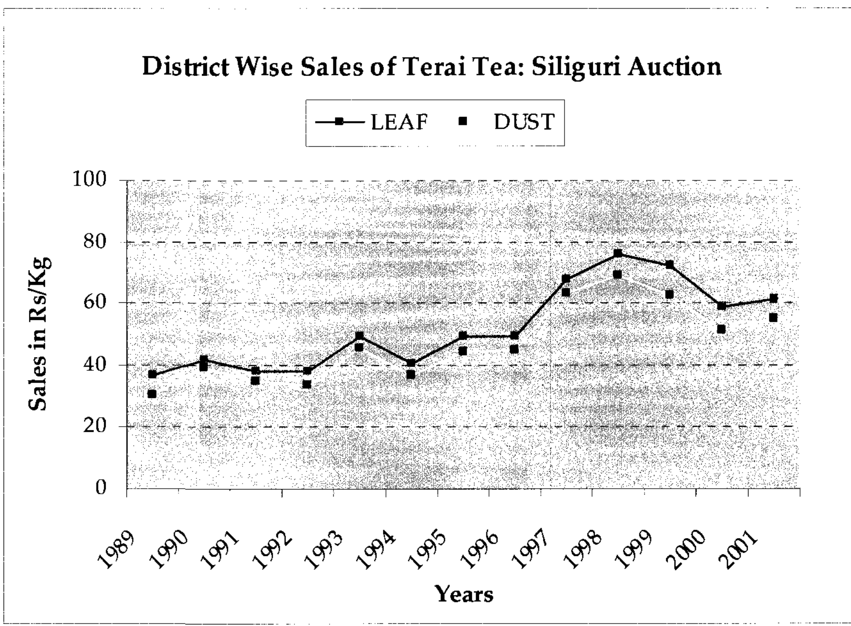


(b)

Figure 41. Total production of Terai tea sold from 1989 to 2001; (a): annual sale in Kolkata auction; (b): annual sale in Siliguri auction.
Source: Tea Board of India.



(a)



(b)

Figure 42. Tea sale prices in Rs/kg from 1989 to 2001; (a) sales at Kolkata auction; (b) sales at Siliguri auction.
Source: Tea Board of India.

8.0. SUMMARY AND DISCUSSION

An initial analysis of the remote sensing data was done for assessment of the spectral signature of the tea bush. The spectral signatures of relevant land covers along different bands were studied and the NIR band was found to be the most sensitive to variations in tea bush health. The NIR band reflectance value for healthy tea bush is approximately 150 DN value, and for unhealthy tea bush the spectral reflectance is approximately 60 DN value. The indices used for analysis included NDVI, NDWI, and the Tasseled Cap transformation, which uses the NIR band as well as bands 1, 2, 3, 5, and 7 bands. The natural color and false color composite images were studied to locate the garden area. The Hansqua Tea Garden and surrounding tea garden of Terai region were considered for the study. The location coordinates of the gardens were recorded during the field visit and the tea bush patches were demarcated and validated with the toposheet map.

According to the Tea Board of India recorded data, the mature tea plants area increased from 1990 to 1999, but the area of aged tea plants decreased in 1999. The unsupervised classification of the Landsat-7 ETM+ data for 1990 and 1999 shows that the area for healthy young shoots decreased in 1999, while the area of senescent tea bush increased, and the stressed or unproductive area also increased. The total production also increased with the increases of total tea bush area calculated from the unsupervised classification; the result matches the trend shown by statistical records. The user-defined NDVI-based classification shows similar correlation with the statistical records of the Tea Board of India.

During the field visit, the managers of Hansqua tea garden were interviewed. According to the managers, production and quality decreases if the plants are old. Therefore, they carry out systematic replanting for increased production as well as improved quality of tea. The management takes care of uprooting and replanting tea bush. They have implemented nursery management, shade tree management, improved irrigation systems, weed management, pest and diseased management for the garden. The statistical record also confirms the results of the uprooting and replanting measures. The age of the tea plants below 5 years in 1999 was 30%, whereas in 1990 the percentage was 9%. The percentage for the stressed or unproductive category also decreased 17% (from 49% to 32%) between 1990 and 1999. The classification results should be interpreted in light of these practices. The percentage for healthy tea bush decreased 21% which was 37% in 1990, and 16% in 1999 because of the process of uprooting and replanting. The tea plant needs three to six years to become productive; in the classification process; the reflected spectral signature of these new plants places them in the stressed and unproductive category. Hence the percentage for stressed or unproductive category shows 39% in 1990 and 51% in 1999 which was increased of 12% in the NDVI-based classification. The percentage of moderately healthy tea bush represents the positive trend as the plants mature in 1999.

9.0. CONCLUSIONS AND RECOMMENDATIONS

The period when the shoot emerges is very important, and care is required for good yield in terms of both quantity and quality. The plucking of tea shoots is still manual, and requires efficient management for determining the precise time and availability of pluckers for the job. If remote sensing technology is applied to the planning phase, the management can plan ahead to derive maximum benefits. As this study shows, a positive correlation exists between the results derived through either unsupervised classification or user-defined NDVI-based classification, with the statistical data of tea yield for the period under study. Management and forecasting techniques on tea yield could be improved using the techniques explored. One of the advantages of this method is that it makes remote monitoring possible and helps decision makers who may be located at some distance from their gardens. The data can be shared and analyzed over the World Wide Web, which not only makes the work flow smoother but also makes it possible to identify and plan activities without the on-site assessment decision makers.

9.1. Questions Answered

i) Can tea plants be realistically identified from easily procured satellite images?

The prime objective is to identify the tea plantation areas or the tea patches from Landsat-7 ETM+ data at a spatial resolution of approximately 30m. The analysis of Landsat data show the healthy, moderately healthy and stressed 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. The image analysis needs expert knowledge for identification of health categories of tea bush.

ii) How helpful are the spectral signatures in the assessment of the features on the ground in the context of tea canopy characterization?

The features were identified in this study by examining the true color composite image and false color composite images. The ground features are also identified by their shape, size, location and surrounding features. The feature like river, lake, rail-road intersection and airport can also be clearly identified in the image. The approximate or anticipated garden areas were demarcated from the toposheet map and overlaid on each image in an ArcView 9.2 environment.

Finally the pixel values were checked and a landuse map with tea patches was prepared.

iii) Is there any relationship between vegetation index NDVI and tea leaf yield?

There was a drop in production in 1999 according to Tea Board of India. The problem started in 1999 due to a drought situation and led to a drastic production shortfall. The NDWI index and Tasseled Cap Wetness index should be analyzed for 1990 and 1999 for further study during drought conditions. The NDWI and Wetness index have been used for tracking changes in plant biomass and water stress in the same manner, water indices can be used for tracking tea bush health. Tea bush is very sensitive to moisture. Drought, as well as high moisture content or water logging in the garden, could lead to a severe production cut. In this study, the NDWI and Tassled Cap Wetness values for healthy and stressed are both compared with NDVI extracted health map for the tea garden area. The Wetness values also show positive relation with NDVI values and tea bush canopy tracking. This study needs to be done carefully as higher NDVI values indicate healthy tea bush canopy. The highest Wetness values represent rivers and open water, and the lowest Wetness values represent bare soil. In this analysis, median values of Wetness show the best results for identifying healthy and stressed tea bush. There are many other factors that also need to be considered for monitoring tea garden and moisture is just one of the criteria for analysis. For more precision higher resolution data can be used for determining moisture levels in short interval spans.

iv) How can the results obtained be helpful in overcoming the problems of conventional tea producing methods?

Using 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. In false-color imagery, the healthy patches are seen as bright red color while the stressed tea patches show up as brownish red or dark brown in color. Identification through imagery will help management to take necessary early action when required (R. Dutta et al., 2005). It will help management to identify and work on the affected areas directly and assess the affect instead of surveying the whole field. Using this simple analysis process, management can monitor the stressed patches in a timely manner, saving time and cost. Systematic plans to remove the severely affected tea patches and applying the necessary control measures for moderately affected plants could be thus implemented based on the analysis.

v) How does the health affect yield of the tea plants as well as the regional Tea market?

There was a downward trend in the production of tea in India during the period analyzed; the record of Kolkata tea auction market also reflects the decline. In 1999, the Siliguri tea auction market reached the highest peak in production in last nine years, along with the recorded increase in land used for tea cultivation. The image analysis shows the area under tea cultivation did indeed increase, but the healthy patches actually decreased in 1999 compared to 1990. The unit price of tea at Indian auction centers registered a decline at Kolkata of 8.48% followed by a decline at Siliguri of 17.03%. The sharp fall in tea prices and down trend market conditions affected the entire tea industry, particularly the producers of Terai region. The image analysis also shows a deterioration of tea bush health consistent with the decrease in quality noted in market price.

9.2. Recommendations

Tea is one of the most important and highest foreign exchange earning agricultural products of India. More research needs to be done using different high resolution sensors to obtain a good classification for tea bush health and apply necessary actions to increase quality and quantity of tea yield. Prior knowledge and field study is essential to carry forward the classification for the interest area. This study was done only based on Landsat images, but airplane-mounted multispectral instruments, aerial photography, and other techniques should be used and results should be correlated to find the most suitable technique. Data should be gathered over short temporal intervals for monitoring plantations, and management should have well-established strategies so that effective measure could be taken when the need arises. Buying satellite imagery or commissioning aerial studies could be very expensive, so short interval monitoring might require strong budget.

Recently, an Unmanned Aerial Vehicle (UAV) was used by National Aeronautics and Space Administration (NASA) to study coffee plantations in Hawaii, and high resolution imagery was made immediately available for assessing field ripeness during the harvest season (Herwitz et al., 2004). Low altitude cost effective UAV platforms may become cost effective as compared to existing airborne or satellite platforms and tea growers could be similarly benefited.

REFERENCES

Bhattacharyya, N., Tudu B., Bandyopadhyay R., Bhuyan, M. & Mudi, R. (2004). Aroma Characterization of Orthodox Black Tea with Electronic Nose. 2004 *IEEE Region 10 conference,* B: 427-430. Retrieved September, 14 2006 from http://ieeexplore.ieee.org

Dutta, R. (2005). Assessment of Tea Bush Health and Yield Using Geospatial Techniques. *GIS Development,* Retrieved September 14, 2006 from http://www.gisdevelopment.net/thesis/thesis7/index.htm

Ghosh, A. & Roy, A. (2005). GIS Anchored Integrated Plantation Management: Tea. Centre for Development of Advanced Computing. *GIS Development,* Retrieved September 13, 2006 from http://www.gisdevelopment.net/application/agriculture/overview/pdf/mi04111.pdf

Hadfield, W. (1974). Shade in North-East Indian Tea Plantations. II. Foilar Illumination and Canopy Characteristics. *Applied Ecology,* 11(1): 179-199.

Herwitz, S. R. et al. (2004). Imaging from an Unmanned Aerial Vehicle: Agricultural Surveillance and Decision Support. *Computers and Electronics in Agriculture,* 44: 49-61.

Jensen, J. R. (2007). *Remote Sensing of the Environment: An earth Resource Perspective.* 2nd edition. Pearson Education, Inc. Upper Saddle River, NJ.

Jensen, J. R. (1996). *Introductory Digital Image Processing: A remote sensing Perspective.* 2nd edition. Prentice-Hall, Inc. Upper Saddle River, NJ.

Panda, R. K., Stephens W. & Matthews, R. (2002). Modelling the influence of Irrigation on the Potential Yield of Tea (Camellia Sinesis) in North East India. Agricultural and Food Engineering Department, Indian Institute of Technology. *Experimental Agriculture,* 39: 181-198.

Patel, N. R. & Dutta, R. (2005). Stein, A., Can Modis derived NDVI provided biophysical status of Tea bush. *GIS Development,* Retrieved September 12, 2006 from http://www.gisdevelopment.net/application/agriculture/yield/rish_1.htm

Rajapakse, R. M. S. S., Tripathi, N. K. and Honda, K. (2001). Spectral characterization and LAI modelling for the tea (Camellia sinensis L. O. Kuntze) canopy. Space Technology Application and Research Program, Asian Institute of Technology. Retrieved September 14, 2006 from http://www.gisdevelopment.net/aars/acrs/2000/ts1/agri001.asp

Saikh, H. (2001). Applying Technique of chemical Fertilizers in the tea Garden. Division of Tea Research, Dholai Tea Estate, Assam.

Serrano, L. U. S. L., Roberts, D. A., Gamon, J. A. & Penuelas, J. (2000). Deriving Water Content of Chaparral Vegetation from AVIRIS Data. *Remote Sensing of Environment,* 74(3): 570-581. Retrieved November, 30 2006 from http://www.sciencedirect.com

Tea Board of India, Tea Statistics. (1989-2001). Government of India, Under Ministry of Commerce & Industry. Retrieved October 17, 2007 from http://teaboard.gov.in/inner2.asp?param_link_id=410&mem_link_name=Tea%20Statistics

The Earth Science Data Interface (ESDI) at the Global Land Cover Facility (GLCF), U. S. Geological Survey (USGS). Retrieved June 21, 2007 from http://glcf.umiacs.umd.edu/index.shtml

U.S. Army Map Service. (1955). India and Pakistan: 1:250,000.The University of Texas at Austin. Retrieved February 16, 2008 from http://www.lib.utexas.edu/maps/ams/india/

Wijeratne, M. A. (2004). Vulnerability of Sri Lanka tea production to global climate change. *Water, Air, & Soil Pollution.* 92(1-2): 87-94.