University of Nairobi

School of Engineering

DEPARTMENT OF GEOSPATIAL AND SPACE TECHNOLOGY

USE OF REMOTE SENSING AND GIS IN TEA MAPPING, CASE STUDY SOUTH IMENTI CONSTITUENCY

BY

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Declaration

I, BENSON MUTUMA MERU, hereby declare that this project is my original work. To the best of my knowledge, the work presented here has not been presented for a degree in any other Institution of Higher Learning.

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BENSON MUTUMA MERU Date

This project has been submitted for examination with our approval as university supervisor(s).

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MR. B. M. OKUMU Date

Dedication

First I wish to dedicate this project to the Lord God Almighty the creator, who is my strong pillar, my source of knowledge, wisdom, understanding and inspiration. He has been my source of strength during the time of this research and to Him I will always be grateful. Second, I dedicate this work to my parents, Mr and Mrs Fredrick Meru who have encouraged me and through financial support making sure I finish that which I have started. Third, to my family members, wife Donnis Kawira and my daughter Shantel Kinya for their moral support. Also without forgetting my sister Nancy Mukami for her assistance with the computer that has contributed mostly in finishing this research. Thank you and may God bless you all.

Acknowledgement

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Abstract

The main aim of this research is to map tea plantations within three tea processing factories (Kionyo, Kinoro, Imenti) in South Imenti Constituency. Further analysis is done to evaluate the number of tea bushes and tea fertilizer needed in these plantation and compare this data with the factories data to check if they correspond.

The process involves processing remotely sensed imagery from Landsat 8 OLI & TIRS using Environment for Visualizing Images (ENVI 5.3) through Supervised Classification and testing Parallelepiped Classifier, Minimum-Distance to the Mean Classifier, Gaussian Maximum Likelihood Classifier for best final results. Also, ground truth data was collected and used as image training data and as ground truthing data.

The results of this study showed that Maximum Likelihood Classifier is the best method for use in mapping tea plantation and vegetation cover at large. This method displayed that, in South Imenti Constituency there are 5,051.61 hectares of land under tea bushes. These hectares translate to 54,557,388 total tea bushes if a standard spacing of 1.2m by 0.75m is used and total of 77,940 tea fertilizer bags calculated from recommended fertilizer application of 700 tea plants per bag of 50 Kgs.

From this study it is concluded that, using Remote sensing and satellite imagery is a faster and less costly method and one can map tea plantations and estimate tea bushes and fertilizer need under uniform tea spacing.

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List of Abbreviations

KTDA	Kenya Tea Development Agency Ltd
ENVI	Environment for Visualizing Images
NDVI	Normalized Difference Vegetation Index
GIS	Geographic Information System
OLI & TIRS	Operational Land Imager and the Thermal Infrared Sensor
RS	Remote Sensing

CHAPTER 1: INTRODUCTION

1.1 Background of the study

1.1.1. History of Tea

Tea (Camellia sinensis) is believed to originate from China at around 2700 B.C. First, it was used as a medicine beverage through boiling of leaves in water, but later at around third century, cultivation of tea started and became a daily drink, which led to the establishment of processing industries. Later at around 800 A.D, tea seeds spread to Japan and 1810 A.D Chinese brought tea farming in Taiwan Island and the various parts of the world. (Tea, Types, & History, 2018)

Tea is the most widely consumed beverage in the world after water. It can be used together with water and sugar or combined with other types of beverages like chocolate, cocoa, coffee and other soft drinks (Lisasteatreasures.com, 2018) Tea plant grows like forest trees of 9-12 meters if not trimmed and like shrubs when trimmed. From legends, tea is believed to contain the medicinal substance that is made from dried leaves and was discovered in China at around 2737 B.C. (Carr, 2018)

In 2013, 4.14 million hectares were estimated to be under tea plants in the world. China takes about 60% (2.47 million hectares of the global total), followed by India with 0.564 million hectares. Kenya comes third with 0.198 million hectares, Sri Lanka fourth with 0.187 million hectares and fifth Turkey with 0.077 million hectares. (ITC,2013)

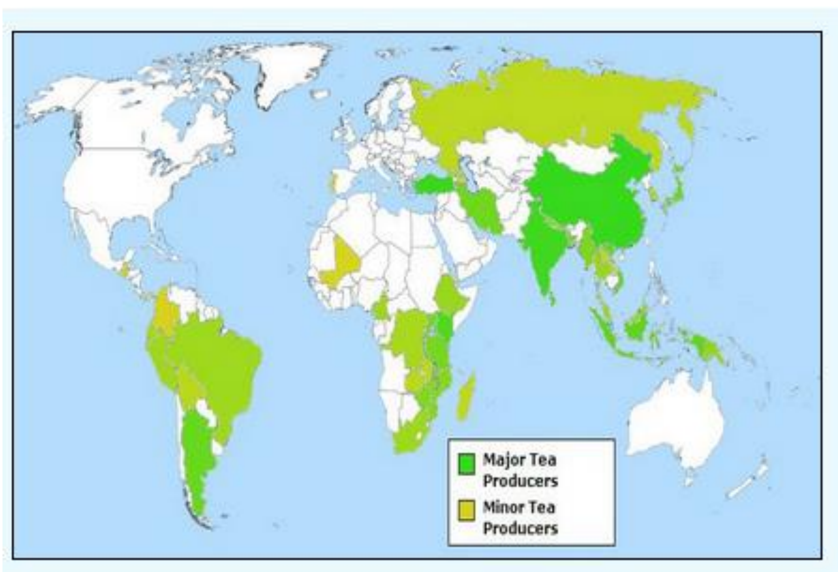


Figure 1.1 Tea regions in the world Source: (Horticulture, 2018)

Figure 1.2 Tea plantation trimmed

Source: RightSmith Company (GmbH, 2018)

1.1.2. Tea in Kenya

In Kenya, tea is among the major cash crop grown and was introduced in the year 1903 and has been commercially grown since the 1920s. It is the largest foreign exchange agricultural earner to the country's economy. There is established Tea Board of Kenya, which is a state corporation responsible for issuing tea growing, manufacturing and export licenses and advises on all matters related to tea. In 1964, Kenya Tea Development Authority was formed and it was mandated with the management of the small-scale farmers, who are to obtain Authority license to plant tea and are only required to sell their green leaf tea after picking through the same Authority. In June 2000, Kenya Tea Development Agency Limited (KTDA) was incorporated as a private company under (CAP 486) the laws of Kenya. KTDA has about 600 000 small-scale tea farmers who are distributed to its 68 tea factories and in an estimated tea farm of about 130 000 hectares in the whole country (KTDA, 2017). There are also large-scale farmers with more than 10 hectares of tea farm who are managed by Kenya Tea Growers Association. In 1986, the Government established another tea corporation and its role was to manage government's tea around the forest zones known Nyayo Zones. (Corporation, 1986)

Tea farming in Kenya is divided into regions according to altitude. Region 1; Aberdare ranges that drop and rise at an altitude of 1700-2200 meters above sea level. Region 2 is around Aberdare forest. Region 3; Around Mt Kenya found within Meru, Embu and Kirinyaga Counties at an altitude of 1500-2200 meters above sea level. It is in this region around Meru County where this study will be based on. Region 4, Nyambene hills at an altitude of 1500-1950 meters above sea level. Region 5 Kericho highlands, located west of Mau Forest at an altitude of 1500-2150 meters above sea level. Region 6 found at Kisii highlands, in the County of Kisii at an altitude of 1500-2150 meters above sea level and Region 7 that is located Nandi hills and in the Western Highlands at an altitude of 1500-2200 meters above sea level. (KTDA,2018)

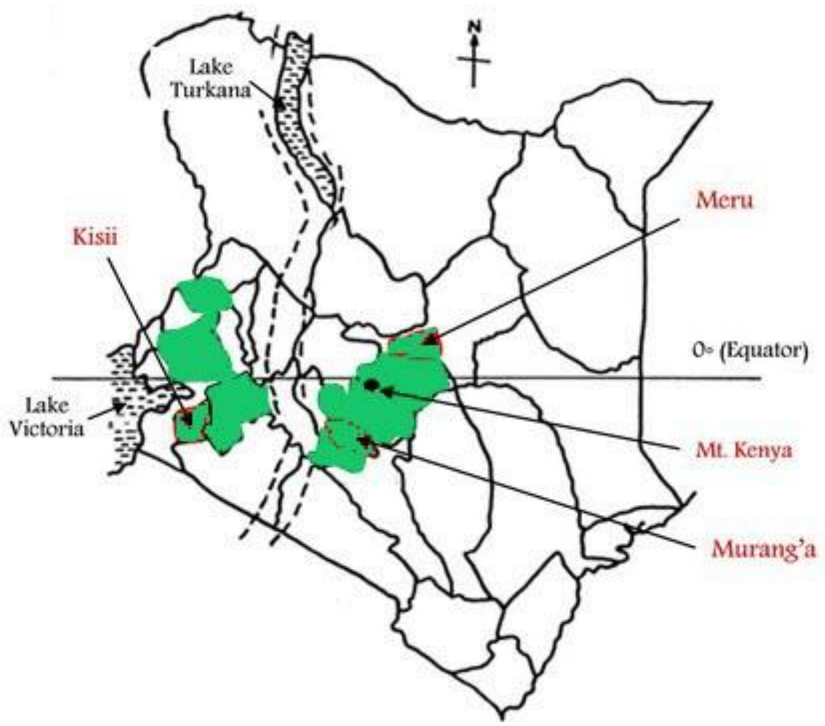


Figure 1.3 Tea Zones in Kenya

Source: American Journal of Plant Sciences (Mose et al., 2014)

There are two types of tea plants grown in Kenya which include, green tea and purple tea. Green tea was grown since 1920s until the year 2011 when purple tea seedling was made available to small scale farmers. Purple tea was discovered at the Assam tea gardens of India and given the scientific name *Camellia sinensis var. assamica*. Assamica means plant is using the Assam cultivar of green tea. It is labelled as TRFK306 which is in the class of green tea. Purple tea have normal green leaves, only that it produces the purple pigments (Purple-tea, 2018).

Figure 1.4 Purple tea

(Source: Superfoodly)

Figure 1.5 Green tea

(Source:Commons,2018)

1.1.3. Tea production in Kenya

According to KTDA 2017 data, Kenya annual tea production in the year 2012 was 369.2 million kilograms that increased in the year 2013, 2014 to 432.2 million and 444.8 million kilograms respectively. Production decreased in 2015 to 399.5 million kilograms and increased in 2016 to 471.4 million kilograms. In 2017, tea production decreased to 439.9 million kilograms. This increase from 2013-2017 was due to increase in crop yield attributed to good rainfall that was distributed well in the tea growing regions, in particular, the first quarter of the year and rapid increase of tea plantations. (Tea Directorate, 2018)

MONTHLY TEA PRODUCTION IN MILLION KILOGRAMS

MONTH	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
January	29.7	25.5	37.7	35.9	36.2	45.3	44.9	41.7	50.3	33.0
February	24.1	21.5	34.8	26.7	18.4	38.5	33.7	24.3	43.9	22.6
March	16.9	18.8	39.2	22.4	17.8	33.3	33.3	15.7	45.3	34.5
April	27.4	18.3	35.9	31.4	18.1	38.2	39.9	23.8	37.6	31.5
May	36.4	29.8	35.6	32.8	37.3	39.6	41.1	37.5	36.6	38.8
June	22.8	25.3	29.8	28.9	30.2	30.5	31.9	32.2	35.9	40.5
July	24.2	21.5	24.4	26.3	24.3	26.2	30.8	30.94	29.3	31.6
August	24.5	21.2	23.1	24.4	31.9	26.3	26.8	28.41	29.5	32.7
September	32	27.4	28.8	30.5	33.5	32.8	33.3	36.84	36.8	38.4
October	35.3	32.8	34.1	39.9	40.2	44.3	45.4	41.34	41.3	43.4
November	34.4	35.9	37	36.8	39.9	35.5	38.6	40.38	39.9	45.4
December	37.9	36.1	38.3	41.3	41.4	41.7	45.1	46.38	45.1	47.5
TOTAL	345.6	314.1	398.7	377.3	369.2	432.2	444.8	399.5	471.4	439.9

Figure 1.6 Tea production in Kenya Source: (Tea Directorate, 2018)

1.1.4. Ecological Requirement for Tea

Tea is grown mostly in highlands, with ambient temperature within 13°C and 28°C-32°C. It is grown at different altitudes in different parts of the world that determine the grades of tea. Example, low grade called Low Crown Tea is obtained from tea grown at an altitude below 610 meters above sea level, Medium Crown Tea obtained from tea grown between 610-2100 meters above sea level and the best quality of tea' High Crown Tea' processed from tea grown at altitudes above 1200 meters above sea level. (Tea Research Association, 2018)

The elevation required is a range from 1000-2500 meters. The best soil required for tea must be light, slightly acidic with soil PH of range 4.5 to 5.5, loam soil with porous sub-soil to allow free movement of water. In regions where there are strong winds and sunlight, planting of large trees in between the lines of tea is encouraged to provide shade for tea and also for tea pickers. During planting spacing can be done in two ways; one-way is Single Hedge system with the spacing of 1.20m by 0.75m that accommodate 10800 plants per hectare. Second, Double Hedge system with the spacing of 1.35m by 0.75m by 0.75m accommodating 13200 plants/ hectare. (Horticulture, 2018)

Figure 1.7 Tea under tree shade Source: (Kericho Tea Hotel, 2018)

Tea is labor intensive ranging from cultivation to processing. It requires human labor to perform most of these tasks like planting, hard picking, weeding, pruning, manuring. Payment for picking is based on the amount of tea one picks in a day. To start a tea farm, a processing industry, and marketing, large amount of money is required to pay workers and for processing.

1.2. Problem Statement

Tea contributes highly to the economy of Kenya, where it is the leading sector in the export of black tea by accounting for almost 20% of foreign exchange of total export earning in Kenya. According to statistics, (Tea Directorate, 2018) tea production and export has increased over the last five years due to the increased number of both small-scale farmers and large-scale farmers. This has helped to reduce the number of unemployed people in the country and mostly in the regions where tea is grown. It is approximated that tea sector has employed over 3 million citizens in various stages of tea farming, from tea land cultivation, planting, tea farm and plant maintenance, transportation, manufacturing in the industry to marketing. KTDA companies also have helped in maintaining the roads to its tea buying centers, which not only benefit the companies but also all citizens who use the roads. Tea is a source of income for farmers and it has reduced the level of poverty in tea regions.

KTDA use manual mapping of tea plantations using farmers title deed and total number of tea bushes calculated manually to estimate the area under tea. This method is costly, time-consuming, and does not indicate the geographical coordinates of these tea farms in a digital map, but they use farmer's title deed to locate the tea farm. This study uses the faster and less costly method (Remote Sensing Technique) and include the geographic coordinates to tea farms for easy monitoring by field officers.

1.3. Objectives of Research

1.3.1. Overall Objective

To map tea farms using Remote Sensing and GIS technology in South Imenti Constituency

1.3.2. Specific Objectives

- To identify the suitable supervised classifier technique for Tea mapping
- To estimate the number of tea plants in South Imenti Constituency
- To calculate the number of tea fertilizer bags required for tea bushes in South Imenti Constituency

1.4. Justification for the Study

As have indicated before, tea sector contributes highly to the income of farmers after selling of tea both locally and outside Kenya. The payment for tea farmers is realized after deductions of cost used by KTDA in transport, processing, and marketing of tea. One of the deductions is the cost used in counting the total number of tea plants by KTDA. This incurs farmers' huge amount of money, it wastes time since counting tea-by-tea plant in more than 130000 hectares every three years it is not an easy task. Sometimes there are risks in the field like hostile weather, which may cause counting of tea plants to stop. In addition, mapping is not carried on some farms due to fencing. Therefore, this study will help the KTDA to realize the importance of Remote Sensing and GIS in mapping tea bushes and will save farmers money.

1.5. Scope and Limitation

1.5.1. Scope

This study focuses on mapping tea bushes in South Imenti managed by three tea factories (Kinoro, Kionyo, and Imenti). Then estimate the number of tea plants according to tea spacing in the region, estimate the number of tea fertilizer bags required in South Imenti and compare it with the three factories data of tea plants and fertilizer required done manually by KTDA. Also, it will test the three supervised classification algorithms (Minimum-Distance to the Mean Classifier, Parallelepiped Classifier, and Gaussian Maximum Likelihood Classifier) and chose the best for tea mapping.

1.5.2. Limitations

In this research, the following will not be on the focus;

- ❖ Identifying the tea bush health in the region
- ❖ Estimating the expected tea yields in the factories
- ❖ Mapping the tea bushes by their age
- ❖ Discriminating purple tea from green tea bushes
- ❖ Mapping tea bushes by their spacing

1.6. Organization of the Report

This report is organized into five chapters, list of references and appendices. In chapter one above, gives the background of tea farming in the world and remote sensing methods. Chapter two presents previous studies or related researches done in mapping vegetation like tea using remote sensing techniques and by use of different satellite imageries. Chapter three elaborates on materials used which includes data sources and tools and methods used to map tea bushes in South Imenti constituency.

Chapter four contains the results obtained after mapping tea using RS and KTDA factories data for comparison. Also in this chapter, discussions are made for the results obtained. Chapter five conclusions are made for results in chapter four and recommendations made for KTDA to adopt and future researches that are needed in tea farming. Lastly, is the reference list indicating the scope of my study and associated knowledge with this report. Also, lists of appendices are indicated which are useful for a reader containing the results not covered in the chapter four and a questionnaire guide used to collect data from the KTDA factories.

CHAPTER 2: LITERATURE REVIEW

2.1. Definitions

2.1.1. Remote Sensing

Remote sensing can be defined as a science or method used to gather information about objects or phenomena on the surface of the earth without actually in contact with the object. It uses the characteristics of the electromagnetic radiation that is reflected or emitted by the earth system to identify features on earth. United Nations in a 95th plenary meeting held on 3 December 1986, defined remote sensing as *means of sensing of the earth's surface from space by making use of the properties of the electromagnetic wave emitted, reflected or diffracted by the sensed objects for the purpose of improving natural resources management and protection of the environment.* (Joseph, 2005)

Factors that help to differentiate various object using remote sensing depends on composition and nature of materials that show different spectral characteristics or signatures. These spectral characteristics help to understand the signature of the earth objects. According to Slater (1980), a ground object spectral signature is a set of measured value for reflectance or radiance of the earth objects with each value with specific wavelength interval. (Slater,1980)

2.1.2. Mapping

Mapping refers to the operation done to represent an element or an area on a map. Increase in population in the earth has caused many resources to be scarce, example tea plantation replacing forest. This scarcity and abundance of different resources have been the effect of land conversion over the whole world. Therefore, these resources require timely and accurate information, like the type, quantity, area/ extent and distribution of resources. It is in this effect that mapping of resources is necessary for easy planning and decision-making. (Congalton and Green, 2009)

2.2. Landsat 8 Satellite

Landsat 8 was developed by NASA and the United States Geological Survey and was launched in February 2013, California, Vandenberg Air Force Base. Its payload consists of two instruments the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). Its provides coverage over the landmass at 30 meters (visible) spatial resolution, 100 meters (thermal) and 15 meters (panchromatic) (Landsat 8 Overview, 2018). Landsat 8 bands are used for different applications (see Table 2.1)

Table 2.1 Characteristics of Landsat 8 OLI & TIRS

Band	Wavelength	Useful for mapping
Band 1 – Coastal Aerosol	0.435 - 0.451	Coastal and aerosol studies
Band 2 – Blue	0.452 - 0.512	Bathymetric mapping, distinguishing soil from vegetation, and deciduous from coniferous vegetation
Band 3 - Green	0.533 - 0.590	Emphasizes peak vegetation, which is useful for assessing plant vigor
Band 4 - Red	0.636 - 0.673	Discriminates vegetation slopes
Band 5 - Near Infrared (NIR)	0.851 - 0.879	Emphasizes biomass content and shorelines
Band 6 - Short-wave Infrared (SWIR) 1	1.566 - 1.651	Discriminates moisture content of soil and vegetation; penetrates thin clouds
Band 7 - Short-wave Infrared (SWIR) 2	2.107 - 2.294	Improved moisture content of soil and vegetation and thin cloud penetration
Band 8 - Panchromatic	0.503 - 0.676	15 meter resolution, sharper image definition
Band 9 – Cirrus	1.363 - 1.384	Improved detection of cirrus cloud contamination
Band 10 – TIRS 1	10.60 – 11.19	100 meter resolution, thermal mapping and estimated soil moisture

Source: USGS, Landsat Missions (Barsi et.al, 2014)

2.3. NDVI (Normalized Difference Vegetation Index)

NDVI is a traditional vegetation index method used to extract vegetation abundance from remotely sensed data (Tucker, 1979). It aims at simplifying data from multiple reflectance bands to a single value correlation to physical vegetation parameters. NDVI separates the difference between the reflectance values in the visible red and near-infrared of the spectrum giving approximate of green vegetation abundance. NDVI is given as. (Jensen, 2007)

$$NDVI = \frac{NIR - R}{NIR + R} \tag{2.1}$$

2.4. Remote Sensing in Vegetation Mapping

In mapping, the use of Remote Sensing and Remote Sensing data has been in use for a long time. Remotely sensed data have been in use to identify the status of vegetation and help the users to take action of any disaster at an appropriate time. In agricultural, several types' research has been done to monitor crop, damage assessment, crop yield estimation, crop suitability and mapping size of land under crops. However, in all those research done, very few studies have been in the tea sector, and in those few, few have used RS and GIS technology. Attempts using Remote Sensing data and GIS have been used to estimate tea yield. (Geospatial World, 2018)

A successful research was done by Isaac Ongong'a Ayuyo, in the Department of Geography and Environment in the University Nairobi and Leonard Swete Regional Centre for Mapping of Resources for Development (RCMRD) to map land cover and land use and change detection of Mau Complex using Geospatial Technology. They applied supervised classification method on Landsat images to classify forestland, other vegetation and non-vegetated land using ENVI 4.8 Remote Sensing software and got the following results. (Table 2.2) (Ayuyo and Sweta, 2018)

Table 2.2 Thematic Cover Class Areas for classified imageries

Class Category	Area			
Cover Type (Class)	AREA (HA) 1973	AREA (HA) 1986	AREA (Ha) 2000	AREA (Ha) 2010
Forest land	286426.08 68%	239994.05 62.8%	243913.15 61.6%	207868.59 53.9%
Other vegetation	92483.64 22%	76844.94 20.1%	55998.46 14.1%	132961.68 34.5%
Non- vegetated Land	42167.88 10%	65505.20 17.1%	96250.57 24.3%	44560.71 11.5%

Source: International Journal of Scientific Research (Ayuyo and Sweta, 2018)

In the study carried on land use and land cover, Global Forest Resources Assessment estimated that world natural forest decreased by 16.1 million hectares per year. They also found that agriculture is the major activity of land cover changes in the tropical regions (Lambin et al, 2001). Sabina N.Baariu and Galcano C. Mulaku in their research to map the total hectares of land covered by Miraa in Meru County using RS, they successfully found that over 70 thousands of hectares of land under Miraa farming and they were able to estimate the regional per capita income from Miraa. (Baariu and Mulaku, 2015)

2.5. Remote Sensing in Tea Mapping

According to the research carried by Rishiraj Dutta of India (2006) on Assessment of Tea Bush Health and Yield Using Geospatial Technology found that, tea industry is losing due to pest and diseases that cause the farmers to uproot tea. He also found that in the area of study using Landsat images displayed results of 60.4% area under health tea, 23.6% area under moderate health tea and 16.2% area under unhealthy tea. This percentage was obtained by calculating the hectares of land in each class of the total hectares of land under study. (Dutta, 2006).

Wellala, Gunatilake and Shyamalie in 2012 carried a study in Sri Lanka using GIS in tea plantation and they were able to classify distributions of various land covers around tea zones and in their results, tea occupied a total of 153.34 hectares which was 64.93% of the study area. Further, information on age and yield estimation of tea was obtained from the images and presented as a digital map (Figure 2.8 and 2.9 below) that helped the field officers in decision making. (Gunatilake et al, 2018)

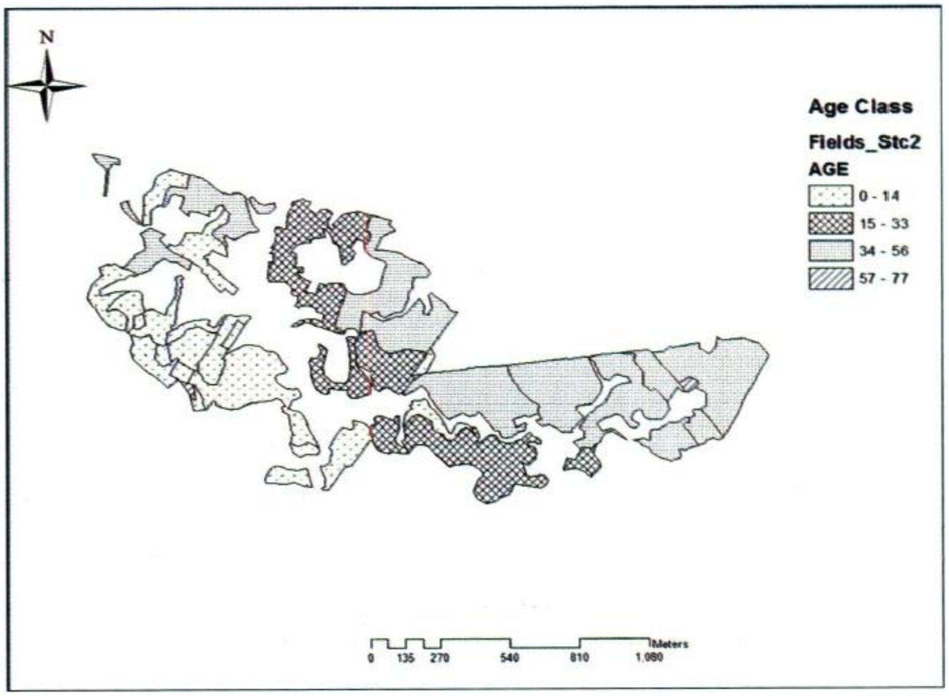


Figure 2.8 Tea plantations by age in Sri Lanka | Source: (Gunatilake et al, 2018)

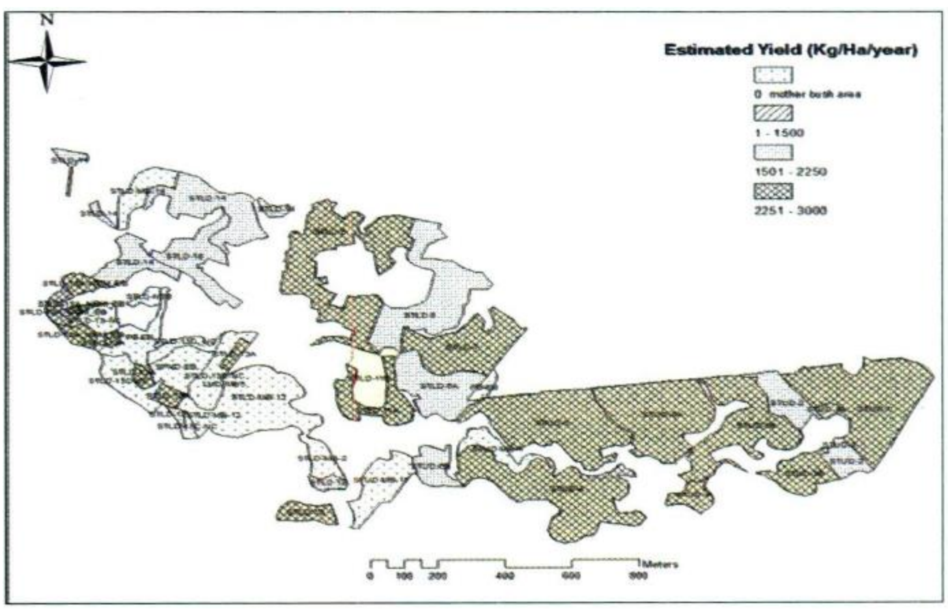


Figure 2.9 Tea yield estimate map in Sri Lanka | Source: (Gunatilake et al, 2018)

The imagery of high spatial and spectral resolution has demonstrated to be very useful for several crops mapping and help to manage agricultural lands. In a research done by Yung-Chung Matt Chuang and Yi-Shiang Shiu of Feng Chia University on the best method analysis for tea crop using worldview-2 imagery found that Maximum Likelihood algorithm had the highest classification accuracy from all other methods used. They found that it is important to map tea, land use and land covers exhaustively and in different agricultural areas because of differences in spatial and spectral resolutions of different land covers. (Chuang and Shiu, 2016)

Previously, in Kenya RS has been used in tea plantation to monitor shoot growth using x-band of SAR that is helpful to estimate tea yield against climatic conditions, identify poorly performing tea patches, help in making decisions in the tea estates and help know where and when to harvest (Snapir et al, 2018). In North East India, studies have been carried using Multispectral RS to map tea that is affected by diseases (Dutta et al, 2008), to examine the replantation phases of deceased tea (Singh,2012) and to evaluate the correlation between tea quality and NDVI (Dutta, 2013).

Therefore, from the above, it is necessary to carry out tea mapping in Kenya using Remote Sensing and Landsat images.

CHAPTER 3: MATERIALS AND METHODS

3.1. Study Area

South Imenti is one of the electoral constituencies in Kenya and one of the constituencies in Meru County. It covers an area of approximately 393.70 km^2 and a population of 178 604 according to 2009 census (Kenya National Bureau of Statistics, 2018). The main economic activities are tea in the upper region, coffee in the lower region and dairy farming.

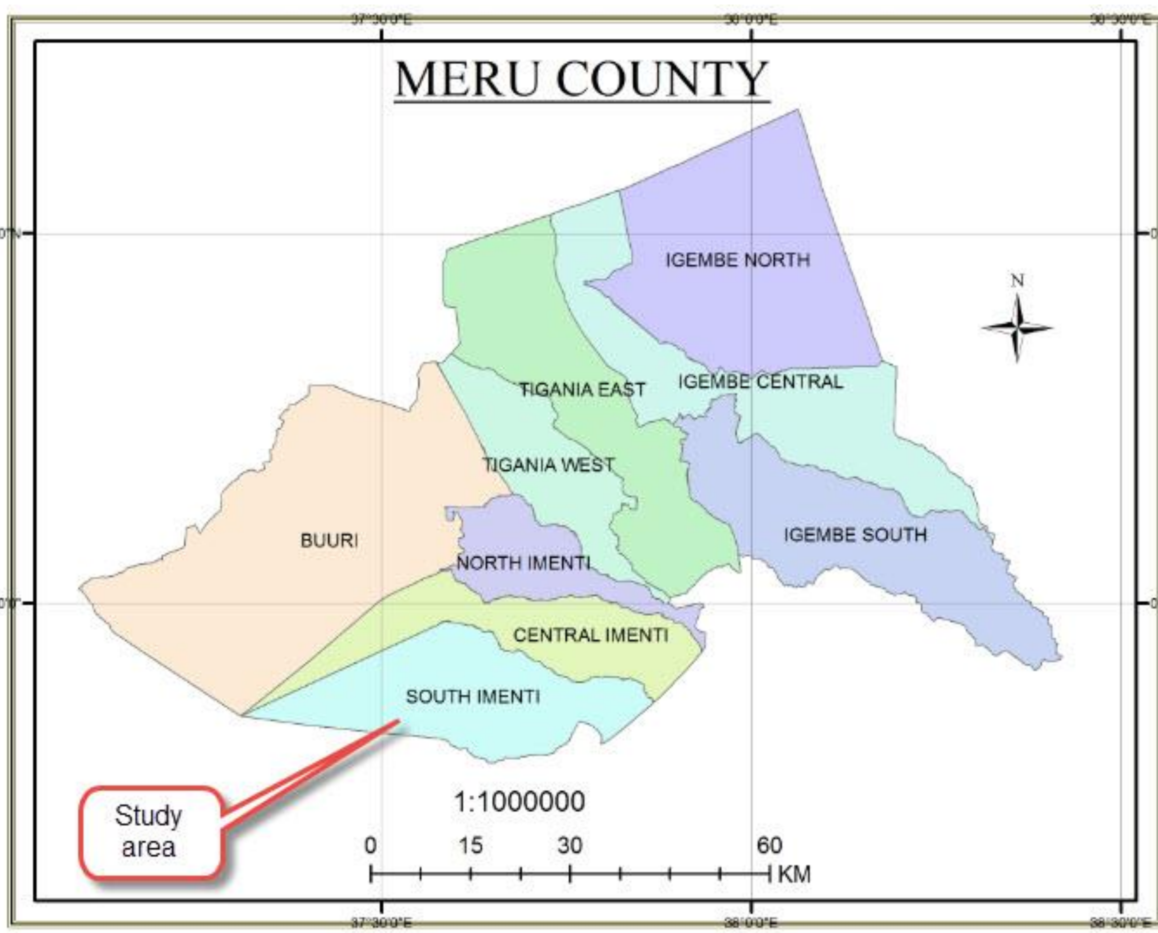


Figure 3.10 Location map of Study Area, within Meru County

Source: (Data.humdata.org, 2018)

3.2. Data Sources and Tools

3.2.1. Data Sources

i. Earth Observation Data

LANDSAT 8 OLI & TIRS image from United States Geological Survey (USGS) acquired on 2018-01-29 was used. Landsat 8 images are acquired already corrected the geometric and radiometric errors and imagery georeferenced by the USGS Agency

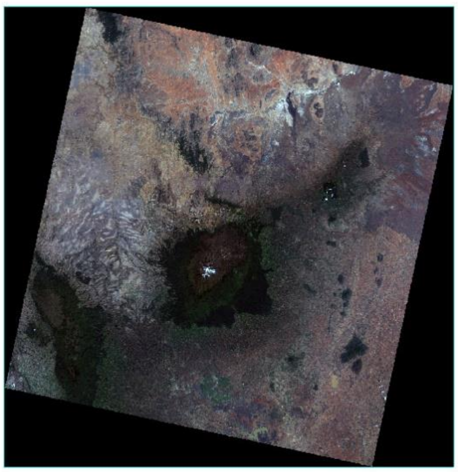


Figure 3.11 Landsat 8 OLI & TIRS Scene

LANDSAT_PRODUCT_ID = LC08_L1TP_168060_20180129_20180207_01_T1

ii. Field Survey Data

Various trips were done to the study area around the tea plantation zone to identify land covers that were used in setting the classification classes. The following classes were chosen for this study (Appendix C):

1. Snow -this was identified from the visual interpretation of the Landsat 8 OLI & TIRS
2. Less Dense Vegetation
3. Dense vegetation which corresponds forest cover
4. Bare soil
5. Built up land
6. Tea vegetation
7. Other vegetation

Also for validating the classification results from the ENVI a remote sensing software, current total tea bushes in the region and total fertilizer bags of 50 kilograms supplied to the farmers last financial year data from the three KTDA factories (Kionyo, Kinoro, Imenti) within South Imenti Constituency was collected (Table 4.10).

3.2.2. Tools

The following tools were used in this study;

1. ENVI 5.3

ENVI was used to process, analyze and extract meaningful information from Landsat imagery.

2. QGIS Desktop 2.16.3

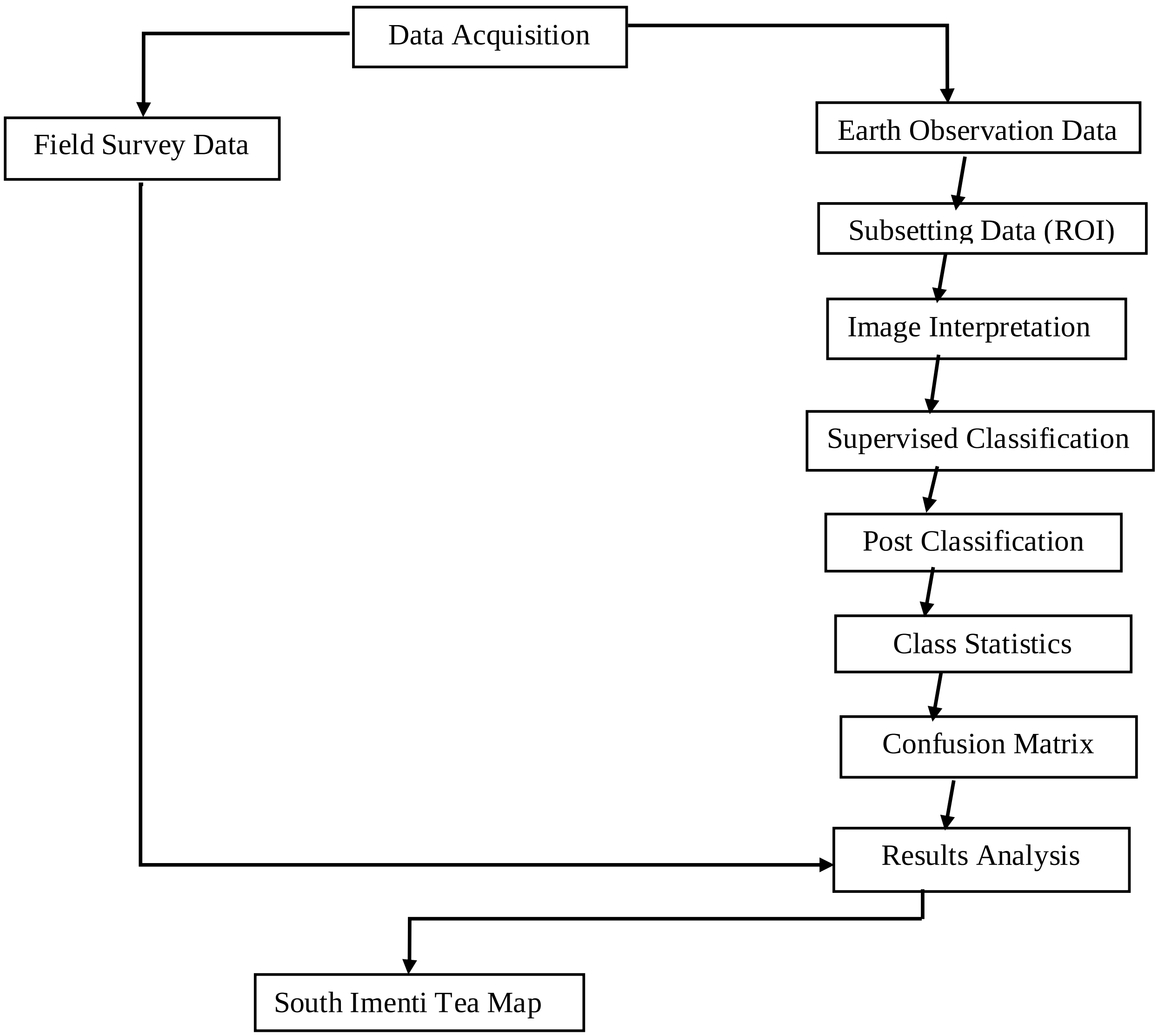
This was used to extract and join X and Y coordinates from the random samples of the classification image and transform to WGS84, ZONE 37S.

3. Global Positioning System and Google Earth

GPS coordinates application was downloaded from google store and installed in the android mobile phone that helped in navigating to the tea plantations and other vegetation in the study area. Also, Google Earth application was installed in the computer and used in coordinates collection and as guide during the classification process

3.3. Mapping Tea

3.3.1. Data Preparation



3.3.2. Image Interpretation

Visual interpretation was done to identify the features in the image. This was done through the following steps: detection of the object, recognition and identification, analysis and classification, field verification.

3.3.3. Image Classification

There are two methods of image classification. One is image analysis based on the pixel; the other is object-oriented image analysis method. For this research, Supervised Classification pixel-based image analysis method was used to classify the feature in the image. In this classification, the user supervises the process by categorizing the pixels in an image through specifying various land cover types in an image. He/ she trains the image to obtain a sample of pixels that are used to classify other pixels in the image with similar characteristics (Wiki.landscapetoolbox.org, 2018).

Together with Supervised Classification, three classification techniques (Minimum Distance to Mean Classifier, Maximum Likelihood Classifier, Parallelepiped Classifier) were performed in the classified image. Then comparison of results for the three classifier was performed, and the most accurate method selected for final output.

3.3.4. Post Classification Analysis

This process was done to obtain the class statistics and assessing the accuracy of the method used in generating the quality map from remotely sensed data (Congalton and Russell, 2009). The following procedures was used to obtain class statistics.

Classification ➡ Post Classification ➡ Class Statistics

This gives the class distribution summary in terms of points and area which can be changed to different units (Acres, Hectares, M^2, etc.).

3.4. Accuracy Assessment

i. Error Matrix or confusion matrix

This refers to the representation of data as row and column as a square having the same number of classes' assessed in an image. Rows represent classification results while columns represent reference data. From Error Matrix the overall accuracy was obtained which is calculated by dividing the total number of pixels that are correctly classified by the total number of reference pixels. Method;

Classification ➡ Post Classification ➡ Confusion Matrix ➡ Using Ground Truth ROI

Equation (3.1) is used to calculate the overall accuracy:

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

(3.1)

In addition, user accuracy and producer accuracy are calculated. User accuracy predicts the probability that the pixel classified to a certain class belongs to that class. Calculated by the following equation (3.2);

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

(3.2)

Producer accuracy estimates the probability that a pixel of a class in the reference classification is classified correctly. Equation 3.3

$$PA(ClassI) = a_{ii} \Big/ \sum_{i-1}^{N} a_{ki}$$

(3.3)

ii. Kappa Statistics

It is a technique used to assess the accuracy of two or more error matrix and determining how one error matrix is more accurate the other (Bishop, 1975). Kappa coefficient is calculated using the following equation;

$$K = \frac{\Pr(a) - \Pr(e)}{1 - \Pr(e)}$$

(3.4)

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1. Results

4.1.1. Region of Interest

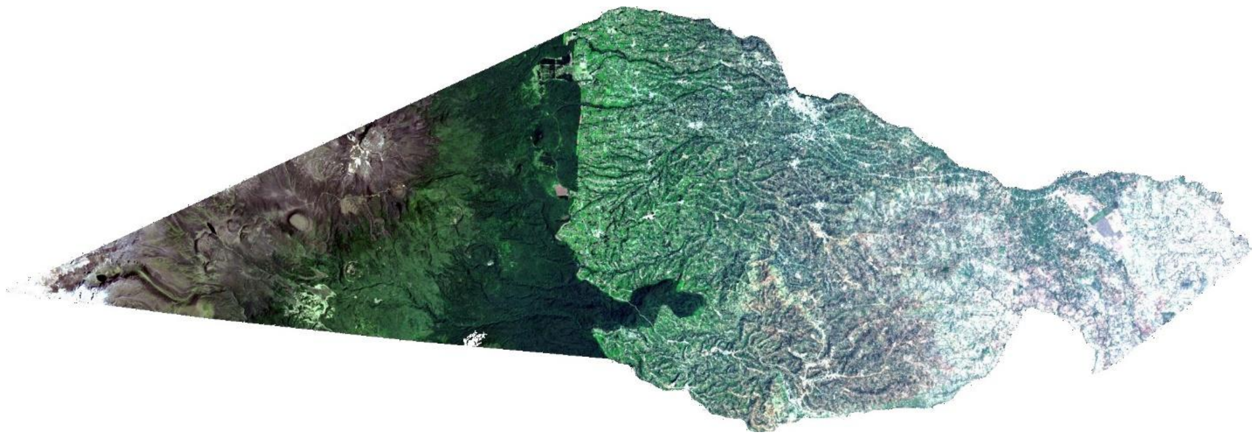


Figure 4.12 South Imenti Constituency Landsat 8 OLI & TIRS image

4.1.2. Maximum Likelihood Classifier

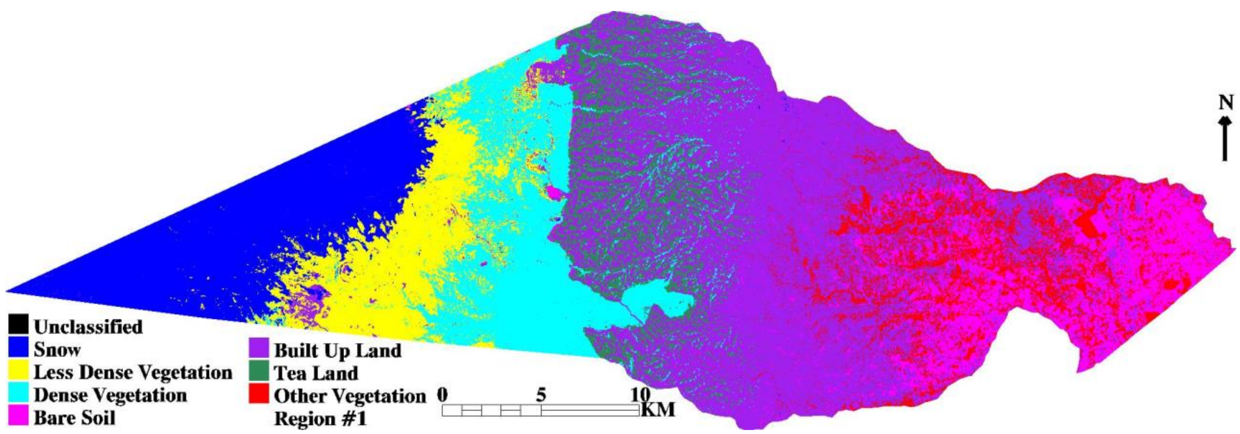


Figure 4.13 Maximum Likelihood Image

Table 4.3 Maximum Likelihood Class Distribution Summary

	Area
Unclassified: 0 points (0.000%)	0.0000 Hectares
Snow [Blue] 30878 points: 106,640 points (7.259%)	9,597.6000 Hectares
Less Dense Vegetation [Yellow] 9351 points: 70,730 points (4.814%)	6,365.7000 Hectares
Dense Vegetation [Cyan] 8371 points: 96,721 points (6.583%)	8,704.8900 Hectares

Bare Soil [Magenta] 1128 points: 73,192 points (4.982%)	6,587.2800 Hectares
Built Up Land [Purple] 2159 points: 267,554 points (18.212%)	24,079.8600 Hectares
Tea Land [Sea Green] 2591 points: 56,129 points (3.821%)	5,051.6100 Hectares
Other Vegetation [Red] 1445 points: 64,837 points (4.413%)	5,835.3300 Hectares
Region #1 [White] 3022 points: 733,343 points (49.916%)	66,000.8700 Hectares

Accuracy Assessment for Maximum Likelihood Classifier

Overall Accuracy = (57928/58945) 98%

Kappa Coefficient = 0.97

Table 4.4 Maximum Likelihood Ground Truth (Pixels)

Class	Snow	Less Dense Vege-tation	Dense Vege-tation	Bare Soil	Built Up Land	Tea Land	Other Vege-tation	Regi on#1	TOTAL
Unclassified	0	0	0	0	0	0	0	0	0
Snow	30751	1	2	0	1	0	0	0	30755
Less Dense Vegetation	69	9086	65	0	0	4	0	0	9224
Dense Vegetation	1	97	8086	0	30	19	0	0	8233
Bare Soil	7	0	0	1096	95	0	10	0	1208
Built Up Land	50	148	132	32	1959	47	28	0	2396
Tea Land	0	19	86	0	39	2521	0	0	2665

Other Vegetation	0	0	0	0	35	0	1407	0	1442
Region#1	0	0	0	0	0	0	0	3022	3022
TOTAL	30878	9351	8371	1128	2159	2591	1445	3022	58945

4.1.3. Minimum Distance Classifier

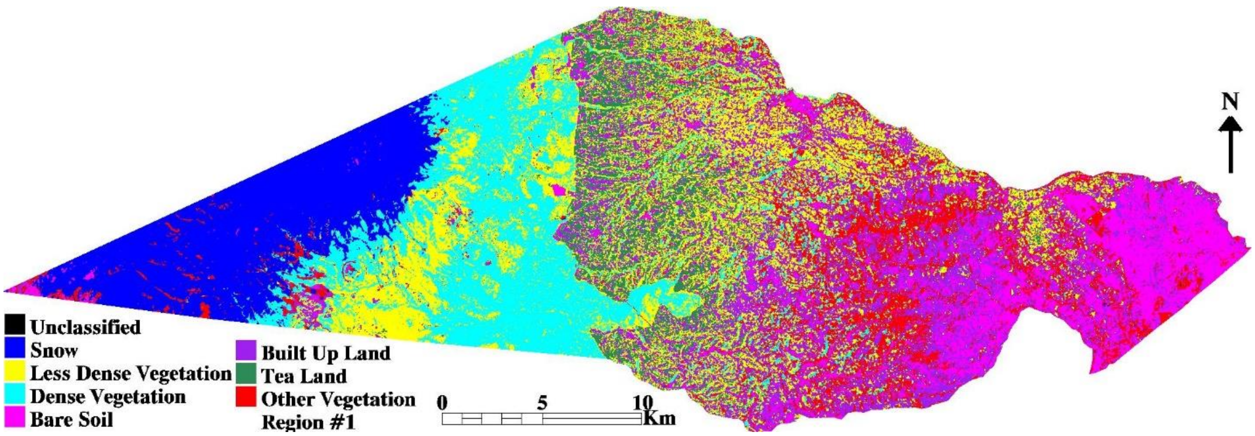


Figure 4.14 Minimum Distance Image

Table 4.5 Minimum Distance Class Distribution Summary

Class	Area
Unclassified: 0 points (0.000%)	0.0000 Hectares
Snow [Blue] 30878 points: 100,051 points (6.810%)	9,004.5900 Hectares
Less Dense Vegetation [Yellow] 9351 points: 158,546 points (10.792%)	14,269.1400 Hectares
Dense Vegetation [Cyan] 8371 points: 129,280 points (8.800%)	11,635.2000 Hectares
Bare Soil [Magenta] 1128 points: 77,145 points (5.251%)	6,943.0500 Hectares
Built Up Land [Purple] 2159 points: 139,644 points (9.505%)	12,567.9600 Hectares
Tea Land [Sea Green] 2591 points: 50,078 points (3.409%)	(4,507.0200 Hectares
Other Vegetation [Red] 1445 points: 81,059 points (5.517%)	7,295.3100 Hectares
Region #1 [White] 3022 points: 733,343 points (49.916%)	66,000.8700 Hectares

Accuracy Assessment for Minimum Distance classifier

Overall Accuracy = (53521/58945) 91%

Kappa Coefficient = 0.86

Table 4.6 Minimum Distance Ground Truth (Pixels)

Class	Snow	Less Dense Vege-tation	Dense Vege-tation	Bare Soil	Built Up Land	Tea Land	Other Vege-tation	Region#1	TOTAL
Unclassified	0	0	0	0	0	0	0	0	0
Snow	29704	1	1	1	4	0	9	0	29720
Less Dense Vegetation	6	8306	1034	0	551	223	38	0	10158
Dense Vegetation	44	798	7305	0	157	0	62	0	8366
Bare Soil	314	0	0	1035	387	0	71	0	1807
Built Up Land	36	82	6	61	716	5	195	0	1101
Tea Land	0	118	18	0	23	2363	0	0	2522
Other Vegetation	774	46	7	31	321	0	1070	0	2249
Region#1	0	0	0	0	0	0	0	3022	3022
TOTAL	30878	9351	8371	1128	2159	2591	1445	3022	58945

4.1.4. Parallelepiped Classifier

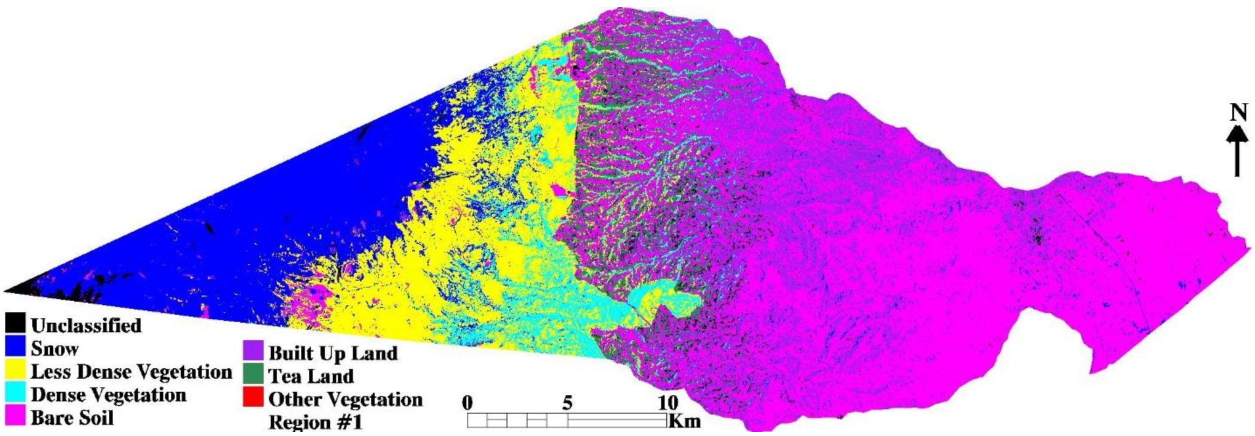


Figure 4.15 Parallelepiped Image

Table 4.7 Parallelepiped Class Distribution Summary

Class	Area
Unclassified: 16,047 points (1.092%)	1,444.2300 Hectares
Snow [Blue] 30878 points: 129,632 points (8.824%)	11,666.8800 Hectares
Less Dense Vegetation [Yellow] 9351 points: 112,900 points (7.685%)	10,161.0000 Hectares
Dense Vegetation [Cyan] 8371 points: 43,685 points (2.973%)	3,931.6500 Hectares
Bare Soil [Magenta] 1128 points: 271,560 points (18.484%)	24,440.4000 Hectares
Built Up Land [Purple] 2159 points: 130,280 points (8.868%)	11,725.2000 Hectares
Tea Land [Sea Green] 2591 points: 31,699 points (2.158%)	2,852.9100 Hectares
Other Vegetation [Red] 1445 points: 0 points (0.000%)	0.0000 Hectares
Region #1 [White] 3022 points: 733,343 points (49.916%)	66,000.8700 Hectares

Accuracy Assessment for Parallelepiped Classifier

Overall Accuracy = (50958/58945) 86%

Kappa Coefficient = 0.80

Table 4.8 Parallelepiped Classifier Ground Truth (Pixels)

Class	Snow	Less Dense Vege-tation	Dense Vege-tation	Bare Soil	Built Up Land	Tea Land	Other Vege-tation	Region#1	TOTAL
Unclassified	651	13	57	5	41	50	0	0	817
Snow	29808	51	349	15	17	0	121	0	30361
Less Dense Vegetation	84	9093	2777	0	39	248	0	0	12241
Dense Vegetation	0	72	5097	0	43	53	0	0	5265
Bare Soil	243	90	13	1108	1298	8	856	0	3616
Built Up Land	92	27	74	0	719	121	468	0	1501
Tea Land	0	5	4	0	2	2111	0	0	2122
Other Vegetation	0	0	0	0	0	0	0	0	0
Region#1	0	0	0	0	0	0	0	3022	3022
TOTAL	30878	9351	8371	1128	2159	2591	1445	3022	58945

4.1.5. Estimated tea bushes and fertilizer bags from the classified images

1 hectare with spacing of 4ft by 2.5ft = 10800 Tea Bushes

700 Tea Bushes = 1 fertilizer bag of 50 Kilograms

Table 4.9 Estimated tea bushes and fertilizer from the classified image

Classifier	Tea land in Hectares	Estimated Tea Bushes	Estimated Fertilizer bags (50 Kgs)
Maximum Likelihood	5,051.6100	54,557,388	77,940
Minimum Distance	4,507.0200	48,675,816	69,537
Parallelepiped	2,852.9100	30,876,228	44,109

4.1.6. KTDA Total Tea Bushes and Fertilizer Bags

Table 4.10 KTDA Total Tea Bushes and Fertilizer Bags

Factory	Tea Bushes	Fertilizer Bags per 50 Kgs
Kinoro	17,945,600	25,600
Kionyo	21,087,176	29,984
Imenti	13,656,202	22,120
Total	**52,688,978**	**77,704**

4.1.7. South Imenti Tea Map

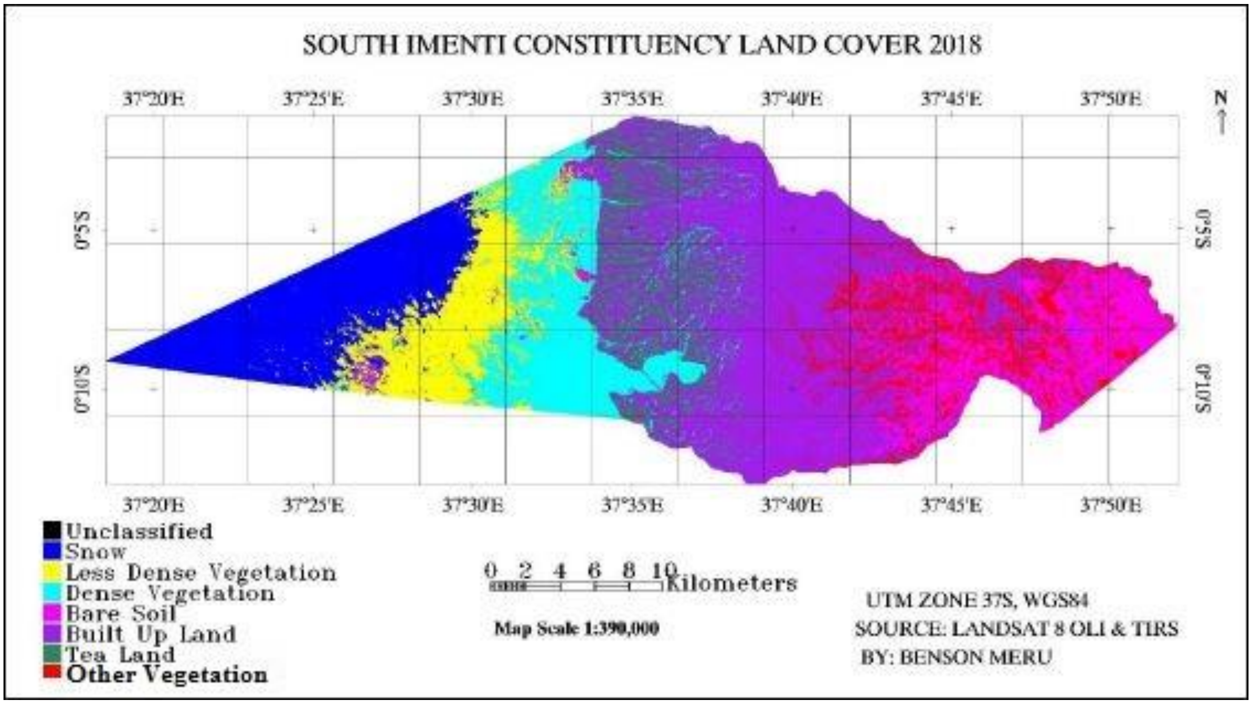


Figure 4.16 South Imenti Constituency Land cover 2018 map

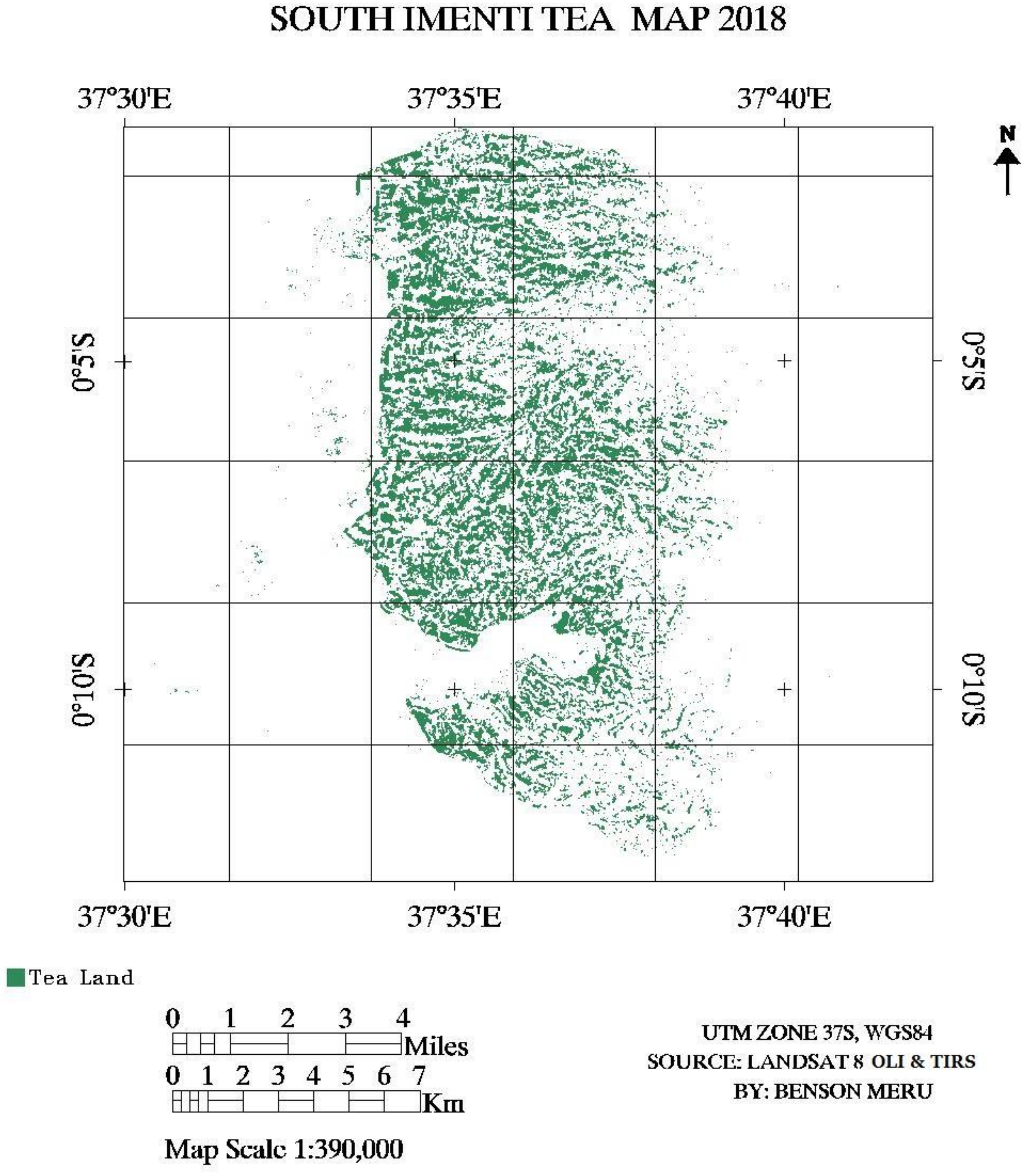


Figure 4.17 South Imenti Constituency Tea Zone map

4.2. Discussion of Results

Studying Table 4.4, 4.6, 4.8, shows that Minimum Distance, Maximum Likelihood and Parallelepiped classifiers have been successful in the land cover classification of south Imenti constituency. Maximum Likelihood classification performed best with overall accuracy of 98% and highest kappa coefficient of 0.97. Minimum Distance classification come second best giving overall accuracy of 91% and kappa coefficient of 0.87. last was Parallelepiped classification which has the lowest overall accuracy of 86% and kappa coefficient of 0.8. This suggest and confirm previous studies results that maximum Likelihood method performs better than the other two classification methods when classifying land covers (Chuang and Shiu, 2016). The reason for the different results produced by these three classification algorithms is due to the different ways in which they use to determine how individual pixel is assigned to a certain land cover type (Horning,2004).

In figure 4.15, Parallelepiped classification created mixed classes classifying Other Vegetation as Unclassified. The spatial resolution of the pixel in these classes generalized the area consisting of different features and makes it hard for the Envi software to classify (Jacquin, et al,2008). This is evidenced in low overall accuracy of parallelepiped classification.

In Table 4.9 and Table 4.10, displays a different result for the total number of tea bushes estimated from classified image and the total tea bushes within the factory. This is due to the different tea plant spacing currently in the region that farmers used during planting. There are three method of spacing found during the field trip; one, single hedge method a spacing of 1.2m by 0.75m which accommodate 10800 plants/hectare. Second, single hedge with spacing of 1.5m by 0.75m accommodating 8500 plants/ hectare and third method was double hedge method a spacing of 1.35m by 0.75m by 0.75m which accommodate 13200 plants/ hectare. In this study a spacing of 1.2m by 0.75m was used to estimate the total number of tea bushes (Table 4.9) in the constituency. From the total number of tea bushes, total fertilizer bags were calculated (Table 4.9) with the factories estimated 700 tea bushes per one bag of fertilizer of 50 Kgs.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

From the results above, Maximum Likelihood algorithm displays a positive result in mapping tea which is more accurate than other algorithms. Maximum likelihood presented 5051.61 Hectares which accommodates 54,557,388 tea bushes and requires 77,940 bags of 50 Kgs tea fertilizer. This was slightly higher than the three tea factories data which was 52,688,978 tea bushes, 77,704 bags of 50 Kgs fertilizer and estimated 4760.1 hectares with a spacing of 1.2m by 0.75m if tea spacing is standard in the region. The final tea farms map for South Imenti (Figure 4.17) was then generated using the Maximum Likelihood classification image since it was the most accurate method.

5.2. Recommendations

Remote sensing has been used more efficiently in mapping vegetation including tea plantations as seen in the results of this study research. Landsat 8 imageries can be used to map tea plantation using the maximum likelihood classifier. It has allowed better decisions to be done, with less cost, and with greater efficiency. KTDA need to use this RS technique rather than manual mapping to save money for its farmers or can be used in other activities within the company. Therefore, Further studies to this are needed on;

- Mapping tea bushes by their age in South Imenti.
- How tea plantation has replaced other vegetation in South Imenti.
- In years to come mapping tea bushes by their varieties (purple tea and green tea) is needed, since during the time of this research only less than 10,000 purple tea bushes were already planted within study area.

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APPENDICES

Appendix A: Interview Guide for KTDA Factory

My name is Benson Mutuma Meru, a student at the University of Nairobi pursuing a Master of Science in Geographic Information Systems. I am conducting a research on the **USE OF REMOTE SENSING AND GIS IN TEA MAPPING IN SOUTH IMENTI.** The information you shall give on this interview will be kept confidential.

1. What are the estimated farmers' total hectares of land with tea in your factory zone?

   ____

2. What are the total estimated tea bushes in this factory zone?

   ____

3. How many kilograms/bags of fertilizer do you supply to your farmers each year?

   ____

4. What is the recommended number of tea plants per a bag of fertilizer during application?

   ____

5. What is the recommended tea spacing in this region?

   ____

Thank you for cooperation, your time and assistance.

Appendix B: Error Matrix

B1: Maximum Likelihood Commission and Omission, Producer and User Accuracy

i. Maximum Likelihood Commission and Omission

Class	Commission (Percent)	Omission (Percent)	Commission (Pixels)	Omission (Pixels)
Snow	0.01	0.41	4/30755	127/30878
Less Dense Vegetation	1.50	2.83	138/9224	265/9351
Dense Vegetation	1.79	3.40	147/8233	285/8371
Bare Soil	9.27	2.84	112/1208	32/1128
Built Up Land	18.24	9.26	437/2396	200/2159
Tea Land	5.40	2.70	144/2665	70/2591
Other Vegetation	2.43	2.63	35/1442	38/1445
Region #1	0.00	0.00	0/3022	0/3022

ii. Maximum Likelihood Producer and User Accuracy

Class	Prod. Acc. (Percent)	User Acc. (Percent)	Prod. Acc. (Pixels)	User Acc. (Pixels)
Snow	99.59	99.99	30751/30878	30751/30755
Less Dense Vegetation	97.17	98.50	9086/9351	9086/9224
Dense Vegetation	96.60	98.21	8086/8371	8086/8233
Bare Soil	97.16	90.73	1096/1128	1096/1208
Built Up Land	90.74	81.76	1959/2159	1959/2396
Tea Land	97.30	94.60	2521/2591	2521/2665

Other Vegetation	97.37	97.57	1407/1445	1407/1442
Region #1	100.00	100.00	3022/3022	3022/3022

B2: Parallelepiped Commission and Omission, Producer and User Accuracy

i. Parallelepiped Commission and Omission

Class	Commission (Percent)	Omission (Percent)	Commission (Pixels)	Omission (Pixels)
Snow	1.82	3.47	553/30361	1070/30878
Less Dense Vegetation	25.72	2.76	3148/12241	258/9351
Dense Vegetation	3.19	39.11	168/5265	3274/8371
Bare Soil	69.36	1.77	2508/3616	20/1128
Built Up Land	52.10	66.70	782/1501	1440/2159
Tea Land	0.52	18.53	11/2122	480/2591
Other Vegetation	0.00	100.00	0/0	1445/1445
Region #1	0.00	0.00	0/3022	0/3022

ii. Parallelepiped Producer and User Accuracy

Class	Prod. Acc. (Percent)	User Acc. (Percent)	Prod. Acc. (Pixels)	User Acc. (Pixels)
Snow	96.53	98.18	29808/30878	29808/30361
Less Dense Vegetation	97.24	74.28	9093/9351	9093/12241
Dense Vegetation	60.89	96.81	5097/8371	5097/5265

Bare Soil	98.23	30.64	1108/1128	1108/3616
Built Up Land	33.30	47.90	719/2159	719/1501
Tea Land	81.47	99.48	2111/2591	2111/2122
Other Vegetation	0.00	0.00	0/1445	0/0
Region #1	100.00	100.00	3022/3022	3022/3022

B3: Minimum Distance Commission and Omission, Producer and User Accuracy

i. Minimum Distance Commission and Omission

Class	Commission (Percent)	Omission (Percent)	Commission (Pixels)	Omission (Pixels)
Snow	0.05	3.80	16/29720	1174/30878
Less Dense Vegetation	18.23	11.18	1852/10158	1045/9351
Dense Vegetation	12.68	12.73	1061/8366	1066/8371
Bare Soil	42.72	8.24	772/1807	93/1128
Built Up Land	34.97	66.84	385/1101	1443/2159
Tea Land	6.30	8.80	159/2522	228/2591
Other Vegetation	52.42	25.95	1179/2249	375/1445
Region #1	0.00	0.00	0/3022	0/3022

ii. Minimum Distance Producer and User Accuracy

Class	Prod. Acc. (Percent)	User Acc. (Percent)	Prod. Acc. (Pixels)	User Acc. (Pixels)
Snow	96.20	99.95	29704/30878	29704/29720
Less Dense Vegetation	88.82	81.77	8306/9351	8306/10158
Dense Vegetation	87.27	87.32	7305/8371	7305/8366
Bare Soil	91.76	57.28	1035/1128	1035/1807
Built Up Land	33.16	65.03	716/2159	716/1101
Tea Land	91.20	93.70	2363/2591	2363/2522
Other Vegetation	74.05	47.58	1070/1445	1070/2249
Region #1	100.00	100.00	3022/3022	3022/3022

Appendix C: Sample Ground Truth Data

F_ID	CLASS_NAME	CLASS_ID	CLASS_CLRS	FILL_CLASS	POLY_TYPE	X_COORD	Y_COORD
1	UNCLASSIFIED1	0	"255,0,0"	1	5	325710	9989110
2	UNCLASSIFIED2	0	"255,0,0"	1	5	329040	9988120
3	UNCLASSIFIED3	0	"255,0,0"	1	5	330780	9987640
4	UNCLASSIFIED4	0	"255,0,0"	1	5	321390	9986440
5	UNCLASSIFIED5	0	"255,0,0"	1	5	322920	9984160

6	UNCLASSIFIED6	0	"255,0,0"	1	5	326730	9983440
7	SNOW1	1	"0,255,255"	1	5	336300	9987970
8	SNOW2	1	"0,255,255"	1	5	334890	9986860
9	SNOW3	1	"0,255,255"	1	5	338160	9989530
10	SNOW4	1	"0,255,255"	1	5	332310	9985330
11	SNOW5	1	"0,255,255"	1	5	331380	9983080
12	SNOW6	1	"0,255,255"	1	5	329670	9982180
13	LESS DENSE VEG	2	"255,0,255"	1	5	335070	9991630
14	LESS DENSE VEG	2	"255,0,255"	1	5	339060	9989380
15	LESS DENSE VEG	2	"255,0,255"	1	5	336930	9988180
16	LESS DENSE VEG	2	"255,0,255"	1	5	336150	9985390
17	LESS DENSE VEG	2	"255,0,255"	1	5	335850	9981730
18	LESS DENSE VEG	2	"255,0,255"	1	5	342000	9982480
19	DENSE VEG1	3	"0,0,255"	1	5	338370	9993820
20	DENSE VEG2	3	"0,0,255"	1	5	343590	9992140

21	DENSE VEG3	3	"0,0,255"	1	5	342720	9990880
22	DENSE VEG4	3	"0,0,255"	1	5	349950	9988660
23	DENSE VEG5	3	"0,0,255"	1	5	341670	9984580
24	DENSE VEG6	3	"0,0,255"	1	5	347040	9982300
25	BARE SOIL1	4	"46,139,87"	1	5	345690	9988780
26	BARE SOIL2	4	"46,139,87"	1	5	347310	9988090
27	BARE SOIL3	4	"46,139,87"	1	5	353040	9990640
28	BARE SOIL4	4	"46,139,87"	1	5	349200	9986290
29	BARE SOIL5	4	"46,139,87"	1	5	355980	9982180
30	BARE SOIL6	4	"46,139,87"	1	5	357420	9980320
31	BUILT UP1	5	"160,32,240"	1	5	336240	9989350
32	BUILT UP2	5	"160,32,240"	1	5	345690	9992380
33	BUILT UP3	5	"160,32,240"	1	5	339210	9990280
34	BUILT UP4	5	"160,32,240"	1	5	339390	9988090
35	BUILT UP5	5	"160,32,240"	1	5	339660	9985840

36	BUILT UP6	5	"160,32,240"	1	5	340620	9984880
37	TEA LAND1	6	"160,82,45"	1	5	350010	9985360
38	TEA LAND2	6	"160,82,45"	1	5	360960	9984310
39	TEA LAND3	6	"160,82,45"	1	5	360840	9981130
40	TEA LAND4	6	"160,82,45"	1	5	367650	9986650
41	TEA LAND5	6	"160,82,45"	1	5	373470	9985780
42	TEA LAND6	6	"160,82,45"	1	5	367590	9982210
43	REGION 1	7	"255,255,255"	1	5	315810	9993760
44	REGION 2	7	"255,255,255"	1	5	312540	9990520
45	REGION 3	7	"255,255,255"	1	5	358230	9995170
46	REGION 4	7	"255,255,255"	1	5	361740	9993010
47	REGION 5	7	"255,255,255"	1	5	334200	9979390
48	REGION 6	7	"255,255,255”	1	5	341520	9977980