Crop Monitoring as an
E-agricultural tool in
Developing Countries

BEST PRACTICE OF CROP AREA ESTIMATION IN KENYA

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EXECUTIVE SUMMARY

The main objective of this work-package is to assess the methodology to conduct crop mapping at different levels in Kenya: at the national and district levels. The work is divided in three parts: the first is to use a high number of high-resolution satellite images to produce a crop map or crop mask at the national level. The second part of activities was to collect the ground truth data at two districts, which are among agricultural production areas in the countries. The third part is to use very high-resolution data to perform selectively the crop area estimation in the some areas of the region. It has been concluded that the field survey en a large area is difficult to be implemented at the country level. A use of remote sensing based approach is recommended. Different pathways for accuracy improvement were suggested.

1. Crop mapping for Kenya using new LANDSAT 8 OLI imagery

1.1. Introduction of a rain fed agriculture

Agriculture remains the most important economic activity in Kenya, although less than 8% of the land is used for crop production. According to the official governmental statistics, 16% of the total area of the country is covered by high or medium agricultural potential land, where the rainfall reaches the minimal level for cultivation. Although the country is broadly self-sufficient for major food needs, the chronic vulnerability to drought is still very present in the arid and semi-arid land where is agricultural potential is low. In drought years, up to 5 million people in these areas require humanitarian assistance.

The natural vegetation distribution in Kenya shows a regional regularity according to the volume of precipitation. From northeast to southwest, along with the precipitation decrease from below 250mm to above 1,700mm, the vegetation distribution of this country shows are change pattern from desert, to grassland, and then to forest. Crops are mainly distributed in the regions with the precipitation above 500mm, while the arable lands sporadically distributed in the regions with less precipitation are mainly the irrigation agriculture; In addition, the south-eastern coastal areas with good seawater conditions are also distributed with some arable lands. In general, the arable lands in Kenya are mainly established based on forest regions.

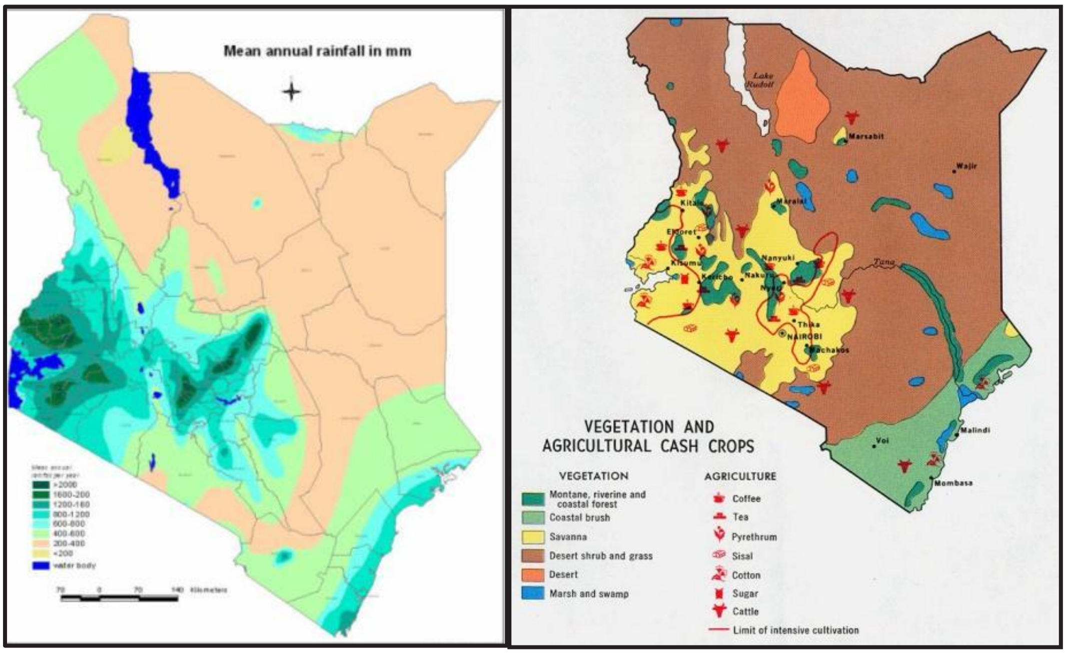


Figure 1: Kenya rainfall and main vegetation distribution

Arable lands in Kenya are mainly distributed in the south-eastern regions with much precipitation, and they are reclaimed based on the original rainforest and mountaintop forest. Due to the enhanced human activities, the forests are degenerated into fragmented type, and replaced by croplands.

According to crop morphology, crop types in Kenya include three strains of tree crop, shrub crop, and herbaceous crop, with a total of 44 types of crops. There are 8 types of tree crops, including 8 coconut, coffee, lemon, limes, apples, pears, orange, mango, and palm; 8 types of shrub crops, including tea, cassava, dal, avocado, yams, Cocoa yam, Ground nuts, sisal hemp; 28 type herbaceous crops, including maize, sugarcane, wheat, rice, sorghum, barley, millet, teff, sunflower, cotton, sweet potato and Irish potato, beans, cowpea, cabbage, cucumber, tomato, watermelon, spinach, lettuce, onion, garlic, pepper, banana, pineapple, rose of Sharon, pyrethrum and tobacco. The country has a total land area of 58.037 million hectares, including 6.15 million hectares of arable lands （FAOSTAT, 2011）, with 13 types of crops of maize, soybeans, dal, cowpea, wheat, sorghum, sweet potato, cassava, millet, coconut, rice, barley and yam. Citrus, mango, banana, sisal and beans can be planted all year round. Majority of other crops are usually sown during March-May and harvested during October-December. Growth period of some crops are relatively short. For example, wheat, cotton and cassava are usually planted during April and May, and harvested during October and November; long rainy season tobacco is usually planted during March and April and harvested during July and August. Crops in Kenya are divided into large rainy season crops and short rainy season crops. Majority of crops are planted during long rainy season, while some crops with short developmental phase, like maize and tobacco, could be planted during short rainy season.

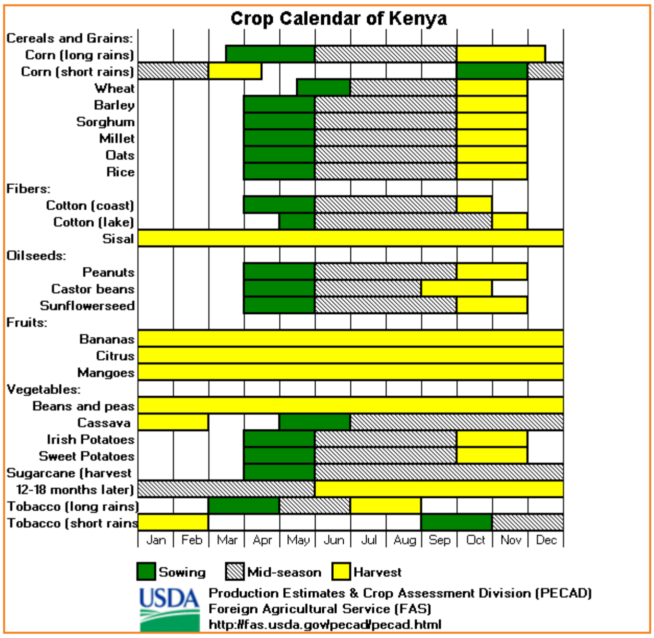


Figure 2: Crop calendar published by USDA

1.2. Satellite imagery and auxiliary data

Data used in this research include two types: vector data of administrative boundary, and remote sensing raster images. Vector data are the zone boundary data from World Resources Institute (WRI， http://www.wri.org/resources/data-sets/kenya-gis-data).

Low resolution remote sensing data include the 16-day synthetic MODIS/NDVI data with spatial resolution of 250m, produced by NASA（http://reverb.echo.nasa.gov/reverb）, from January 1 to December 30th of 2013, with a total of 23 periods. The projective mode of UTM Zone 37 North and geodetic coordinate system of WGS 84 spheroid is used. Figure 3a provides the false colour composite map at April 23rd, July 28th, and September 30th of 2013.

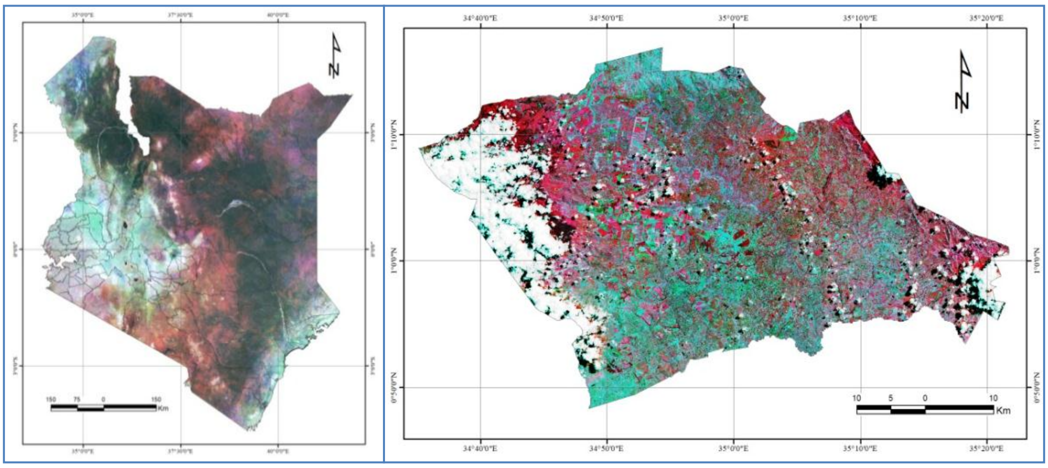


Figure 3 MODIS/NDVI False Color Composite (left, a), Trans Nzoia Region OLI False Color Composite Image (right, b)

High-resolution Landsat 8 OLI data used in this research have a spatial resolution of 30m. The data were collected from NASA（http://ids.ceode.ac.cn/query.html). A total of **32** OLI scenes are required to cover the entire country. The project has acquired 138 scenes from April 1st to September 30th of 2013, including 19 scenes in April, 33 scenes in May, 24 scenes in June, 28 scenes in July, 26 scenes in August and 8 scenes in September. UTM Zone 37 North is taken as the projection mode, and WGS 84 coordinate system is taken as the geoidal surface. All data use ENVI/FLASSH module to perform atmospheric correction. Except for cirrus cloud waveband (the 6th waveband), all 1-8 wavebands are classified. Figure 3b illustrates the OLI-NR, R, B false colour composite image of Trans Nzoia region of April 19th 2013.

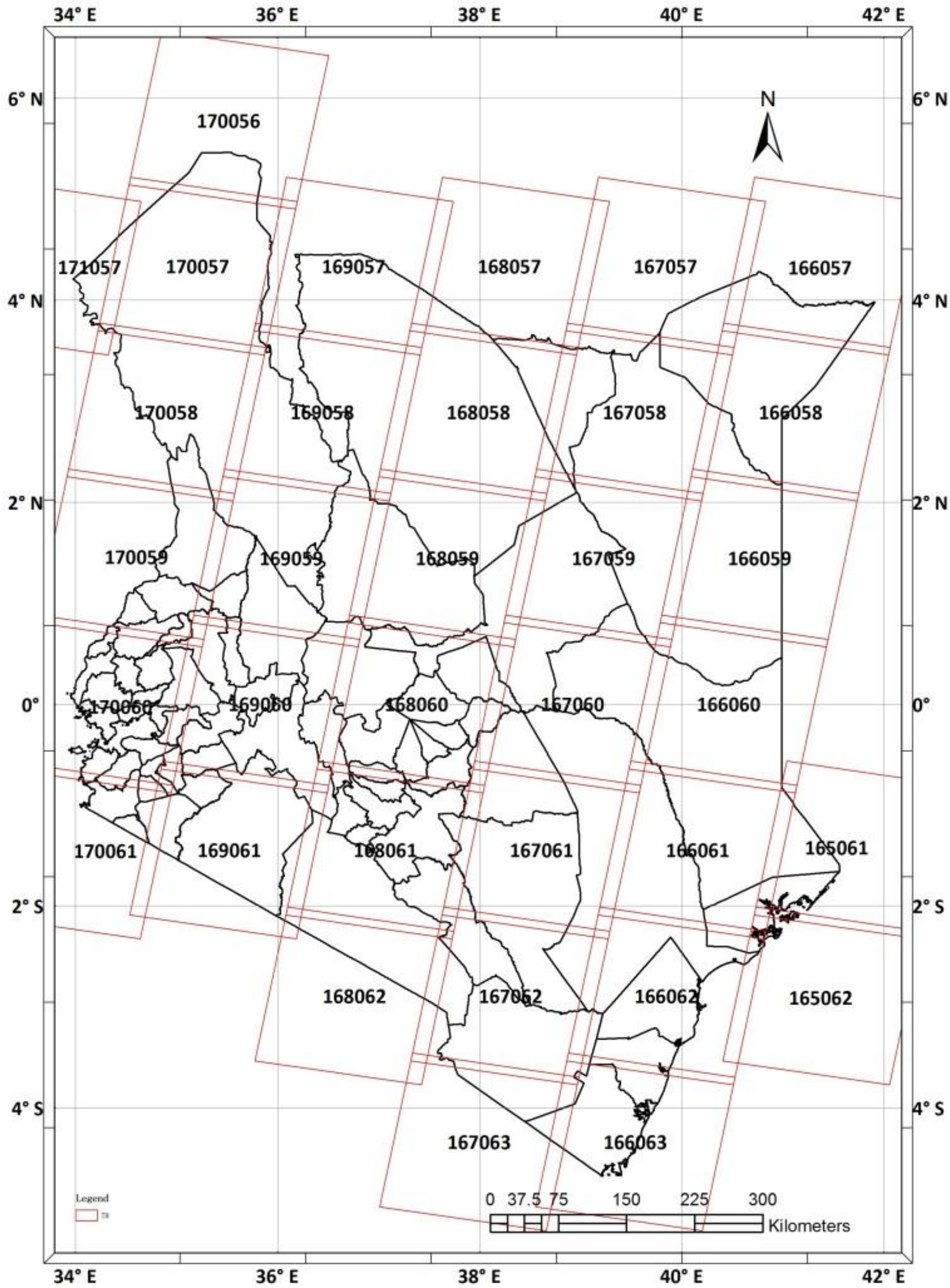


Figure 4: Landsat 8 OLI coverage for Kenya

1.3. Pre-processing of satellite data

The 16-day maximum-value composite EOS/MODIS/NDVI data were acquired. Data smoothing is conducted by using “Savitzky-Golay” filter.

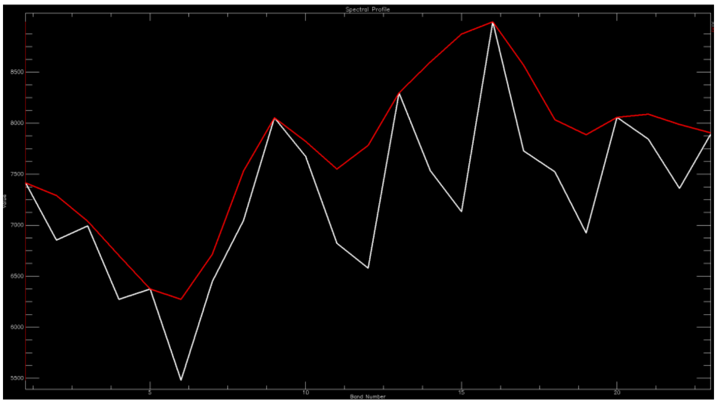


Figure 5: comparison before and after conducting Savitzky-Golay filtering (before filtering is white, and after filtering is red)

ENVI/FLASSH module was used to perform atmospheric correction. Except for cirrus cloud waveband (the 6th waveband), all 1-8 wavebands were included for further classification analysis. Figure 3b illustrates the OLI-near-infra red, red, and blue false color composite image of Trans Nzoia region registered on April 19th 2013.

1.4. Methods of image classification and crop area extraction

This section elaborates the technical approach aiming crop area extraction in Kenya. It mainly consists of two levels: the first level is to use 2012 MODIS NDVI 16 daily composites with the spatial resolution of 250m. The time series contain 23 images. The unsupervised classification ISO-data method was used to:

- pre-classify the total areas of the country into 100 classes,
- extract the NDVI spectral profiles of pre-determined 100 end-members.
- identify each type by using GoogleEarth data;

The identification led to a merge of 100 classes into 26 classes, which are the currently preliminary vegetation distributions extracted in Kenya. To demonstrate the regional regularity of the vegetation distribution, the above 26 classes are further merged into 7 classes (Figure 6 and Figure 7).

From this investigation using MODIS data, The Spatial distribution and area of the arable land for the country have been determined and extracted (Figure 8). Table 1 show the figures obtained by the MODIS data classification and the official national crop area data published by FAO.

Table 1: Kenya Crop Areas based on MODIS Data

Crop type	Source of data	Quantities
Arable land	MODIS Remote sensing data	5.8993 million hectares
Arable land	FAO statistical data of 2011	6.15 million hectares
Arable land	Relative difference	-4.1%

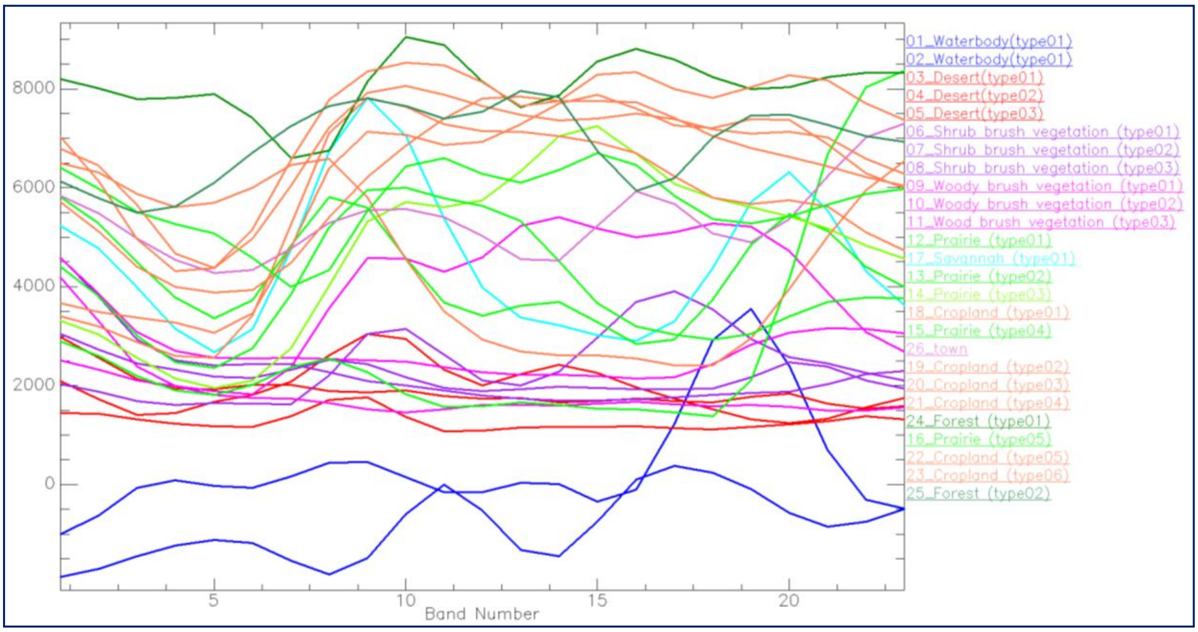


Figure 6: The spectral profiles of 100 land use-classes obtained from ISODATA classification

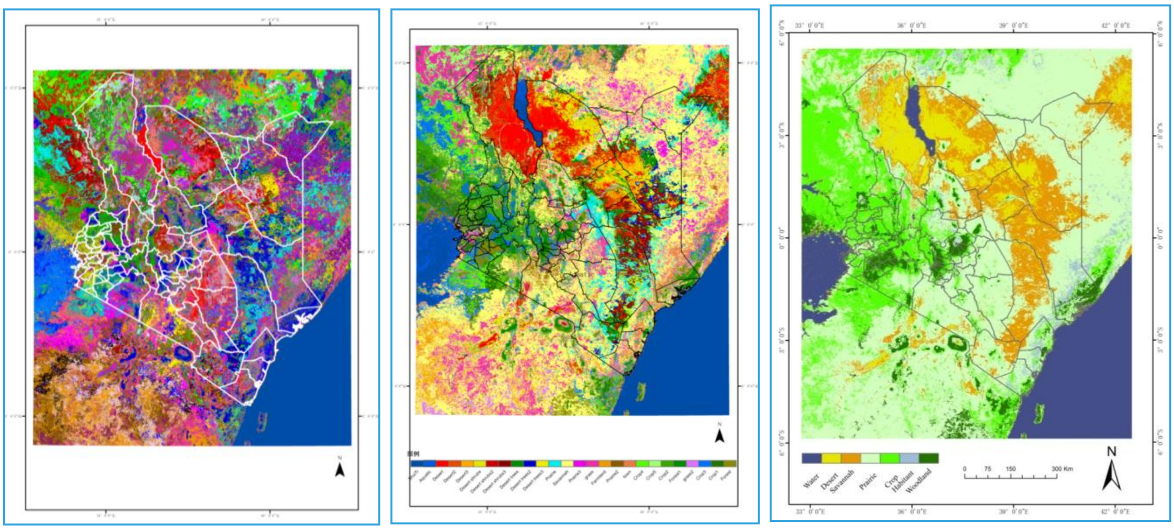


Figure 7: The land use maps of the countries with 100, 26 and 7 classes (end-members)

However some inaccuracy may be generated during the merge from 100 land-use classes to 26 ones. For this reason, reclassification on OLI data was conducted using the agricultural land classes from MODIS classification as mask. As the country has a large area, which needs 32 scenes of OLI to cover the whole country, crop mapping using OLI data has to be carried out in a smaller administrative level. The first test was carried out in the region of Trans Nzaoia. For that region, the unsupervised classification on OLI images was conduct for the identification of crops by using the crop spectral features or profiles established earlier. Using this approach the extraction of maize area has been performed (Figure 9)

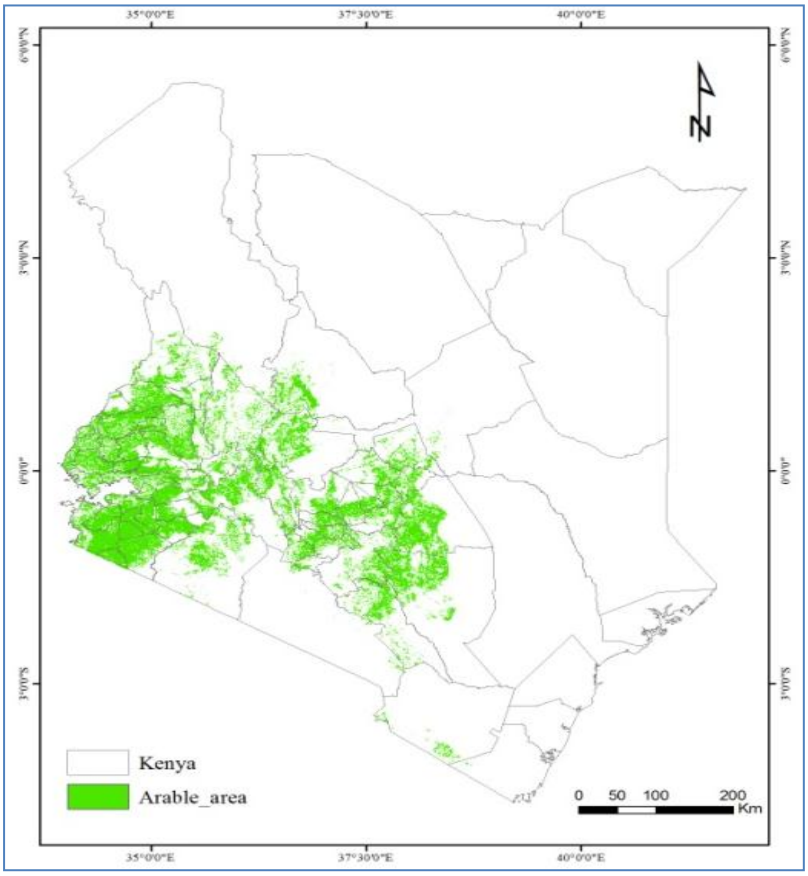


Figure 8: Kenya Arable Land Area Distribution

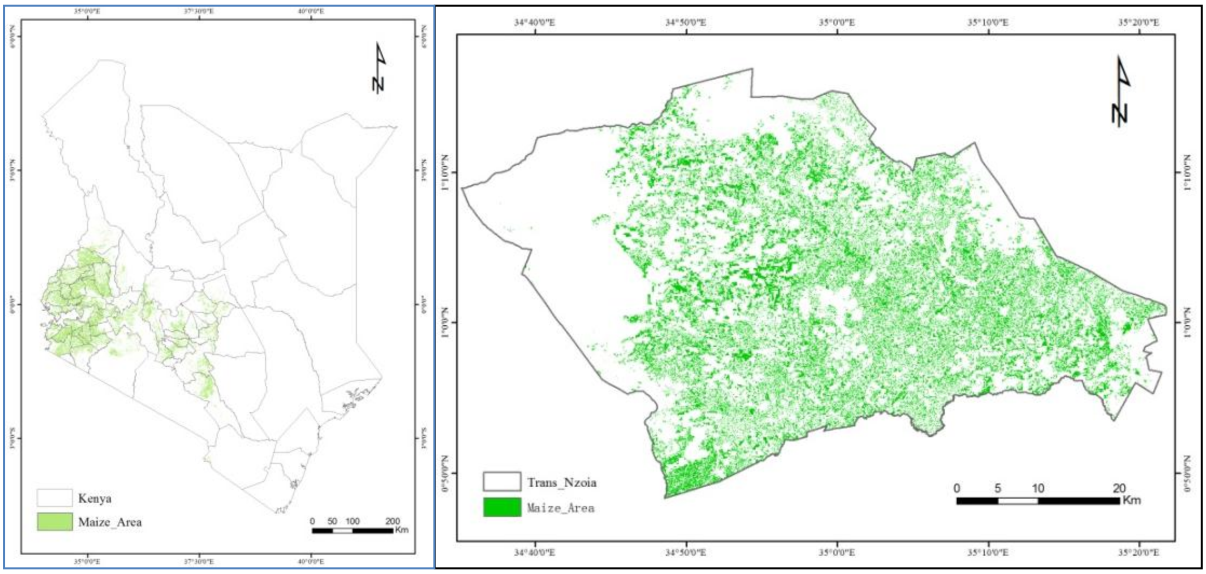


Figure 9: Kenya Maize Spatial Distribution (a, left); Trans Nzoia County Maize Spatial Distribution (b, right)

The validation of the mapping for maize at country and regional levels were conducted. The table 2 compares the estimates published by USDA and the figures extracted from this research.

Table 2: Kenya Maize Areas based on OLI data analysis versus those published by USDA

Crop type	Source of data	Kenya
Maize	OLI remote sensing data	2.1862 million hectares
Maize	2013 data predicted by USDA	2 million hectares
Maize	Relative Difference	+9.3%

The validation of maize mapping was performed using GoogleEarth image, and digitalization of OLI images. A total of 10 verification samples are selected. Figure 7 provides the contents of the distribution of verification samples, OLI local image, GoogleEarth image, and boundary of ground sample. Confusion matrix of validation is shown in Table 3.

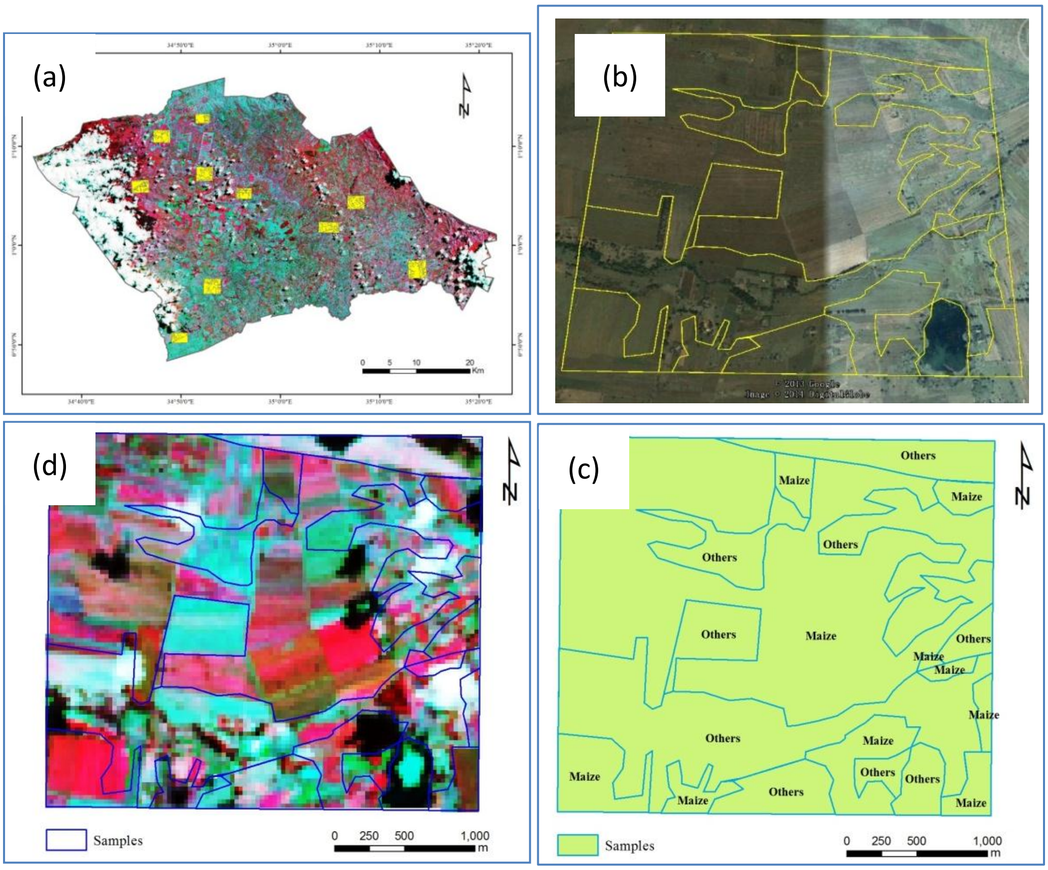


Figure 10: Maize Precision Verification of Trans Nzoia County

(a) OLI Image and Ground Sample Distribution of Trans Nzoia County

(b) GoogleEarh Image of Ground Sample

(c) Enlarged Drawing of OLI Image and Ground Sample Distribution

(d) Partial Enlarged Drawing of Verification Sample

Table 3: accuracy of OLI Maize Area Extraction of Trans Nzoia County

Crop type	Maize	Others	Mapping accuracy (%)
Maize	33800	5098	83.8
Others	6558	37549	88.1
User accuracy (%)	86.9	85.1	
Overall accuracy (%)	86.0		
Kappa Coefficient	0.72		

2. Area frame sampling in two study areas of Kenya

2.1. Study areas of Kamamega and Butere Mumias

Kakamega District is located in the western part of Kenya and covers an area of 1,395 km2. The larger district has seven divisions: Kabras, Shinyalu, Navakholo, Lurambi, Ikolomani, Ileho and Municipality divisions. The projected district population from the 1999 population census is 690,000 persons. Average population density is 495 persons per km2. The district lies within altitude 1,250m-2,000m a.s.l. with the average annual rainfall ranging from 1250-1750mm p.a. Average temperature in the district is 22.50C most of the year. Dominant crops in this region include grain maize (B13), Ground beans (B42), millet (B12), sugarcane (B35) and vegetables (B46).

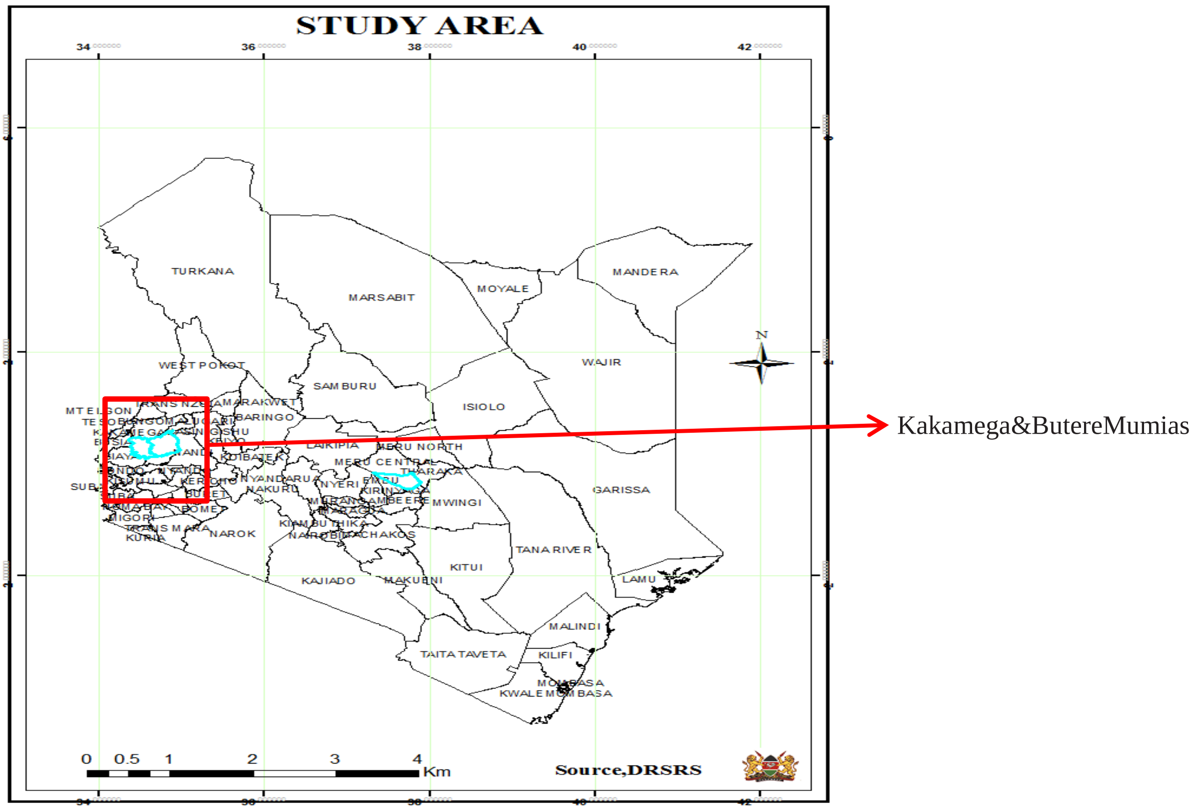


Figure 11: the study areas in this research activity

Butere Mumias District lies at an altitudes of between 1240 m and 1641 m above sea level. The district has 7 streams which serve as the main sources of water for the residents.The main crops are Sugarcane, tea, Sunflower and soybeans as cash crops and maize, beans, sweet potatoes and bananas as food crops. They also produce some fruits namely avocado, pawpaw, bananas and pineapples.

2.2. Preparation for the field survey

Various maps were prepared using Quantum GIS software. The maps included point map, tile map, aerial photo cluster maps and field orientation maps. The purpose of the field orientation map in addition to the GPS and individual Geographical knowledge was to enable the officers identify easy access roads/routes to the points.

Field orientation maps were prepared for each team with assigned sample points, road network and drainage pattern overlaid. A total of six field orientation maps were prepared using ARCGIS software.

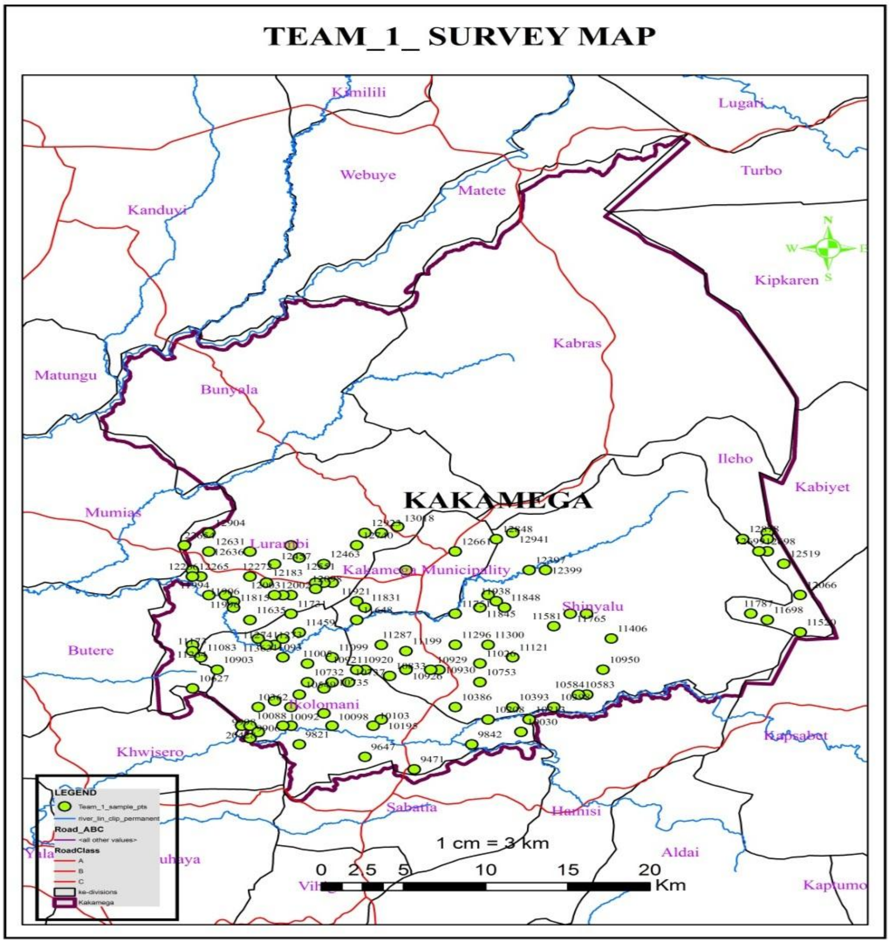


Figure 12: Kakamega point survey location

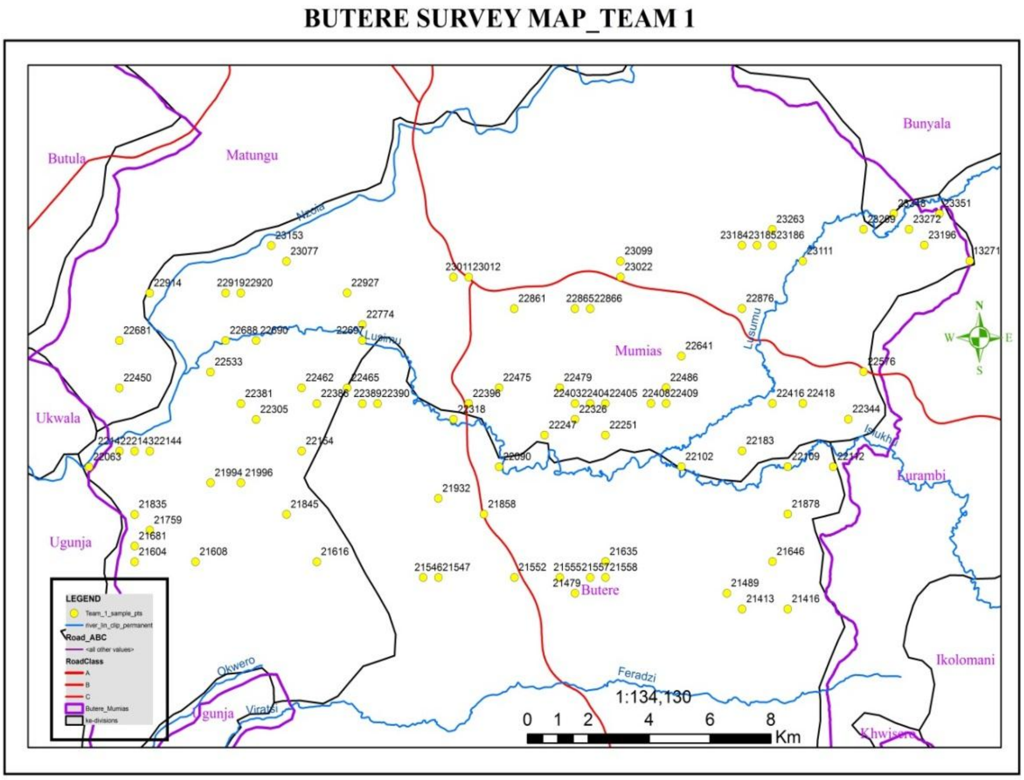


Figure 13: Butere survey point location

2.3. Execution of field survey

Prior to the survey, photo interpretation was conducted in the office. Photo filtration was also performed and points to be verified on the ground selected. Extend of ground observation generally depended on the type of interpretation, accuracy requirements, quality of the photographs and the interpreters' knowledge of the local conditions. Land use practices vary according to tradition, climate, soil, type of crop and condition of the market. In some areas, distinct variations occurred between adjoining farms. Field observations therefore played an important role in giving adequate weight to these variations.

Kakamega and Butere had a total of six hundred and fifteen (615) filtered sample points and one hundred and eighty five aerial photo clusters (185). The points and aerial photo clusters were distributed amongst the three teams as follows:

KAKAMEGA

TEAM	TEAM LEADER	SURVEYOR CODE	ASSIGNED POINTS	AERIAL PHOTO CLUSTERS
1	HesbonKamulla	S_10	115	33
2	Joel Katembu	S_07	112	20
3	JoanesRapando	S_08	120	19
	TOTAL		**347**	

BUTERE MUMIAS

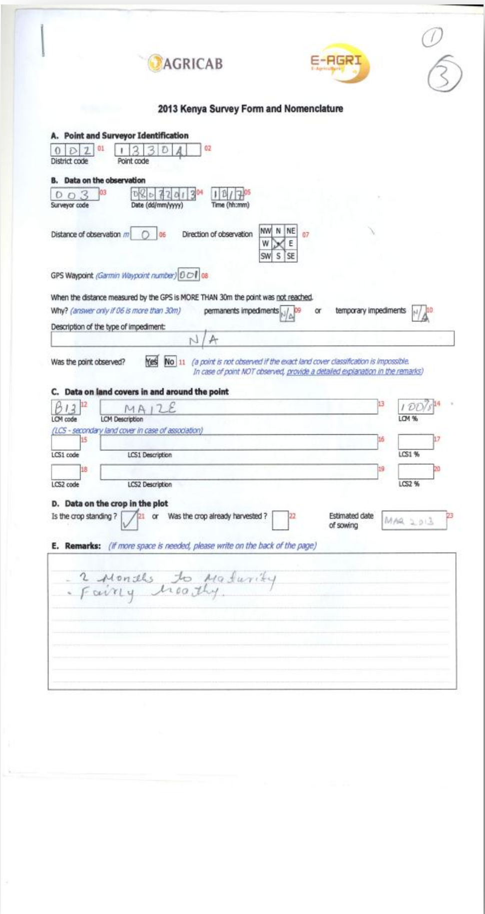
TEAM	TEAM LEADER	SURVEYOR CODE	ASSIGNED POINTS	AERIAL PHOTO CLUSTERS
1	HesbonKamulla	S_10	91	16
2	Joel Katembu	S_07	88	16
3	JoanesRapando	S_08	89	17

Before the actual survey, a field orientation was conducted for one point in the presence and participation of all the three team members. The purpose of this was to finally synchronize the field methodology to all members and specifically have a standardized way of sampling in reference to the implementation manual. Members at this stage were able to practically see how to classify and interpret complex associate land cover classes as earlier outlined during the training.

Point frame sampling was the main component in the survey procedure. Point frame sampling was performed as per survey guidelines in the manual. The surveyor ensured that A4 photo-maps of each point showing its location and code, tile map, topographical map (base map), field forms, active and fully charged GPS were available. The survey involved optimal route planning, approach to point using the GPS directional compass, access and identification of the point, collection of data on the observations made, data on land cover in and around the point, data on crop in the sample plot and recording general remarks in the field form. Most of the remarks were generated from questionnaires administered to local farmers and particularly knowledge by the officers from Ministry of Agriculture.

Field data collection at this stage involved recording the point code, surveyor (team no.) code, date, time of survey, distance of observation indicated by the GPS, direction of observation, saving the waypoint from where the observation is made and classifying in percentages the main land cover type at the point.


Figure 14: members from left,Sarah,Vincent and Hesbon discussing class association and right Sarah marking a reached sample point.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2013 Kenya Survey Form and Nomenclature

A. Point and Surveyor Identification
002 (01) District code — 13304 (02) Point code

B. Data on the observation
003 (03) Surveyor code — 08072013 (04) Date (dd/mm/yyyy) — 10/7 (05) Time (hh:mm)

Distance of observation m: 0 (06) — Direction of observation (07): NW N NE / W E / SW S SE

GPS Waypoint *(Garmin Waypoint number)* 001 (08)

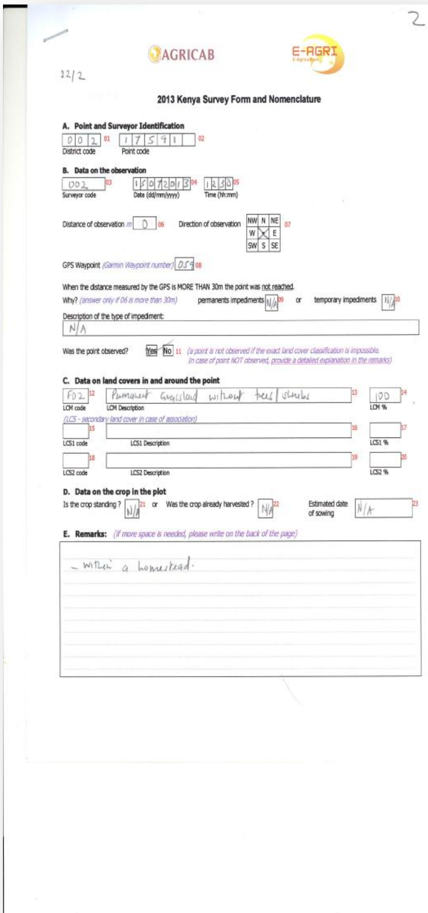
When the distance measured by the GPS is MORE THAN 30m the point was not reached.
Why? *(answer only if 06 is more than 30m)* permanents impediments N/A (09) or temporary impediments N/A (10)
Description of the type of impediment: N/A

Was the point observed? Yes No (11) *(a point is not observed if the exact land cover classification is impossible. In case of point NOT observed, provide a detailed explanation in the remarks)*

C. Data on land covers in and around the point
B13 (12) LCM code — MAIZE (13) LCM Description — 100% (14) LCM %
(LCS - secondary land cover in case of association)
(15) LCS1 code — (16) LCS1 Description — (17) LCS1 %
(18) LCS2 code — (19) LCS2 Description — (20) LCS2 %

D. Data on the crop in the plot
Is the crop standing? ✓ (21) or Was the crop already harvested? (22) Estimated date of sowing: MAR 2013 (23)

E. Remarks: *(if more space is needed, please write on the back of the page)*
- 2 Months to Maturity
- Fairly healthy.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2013 Kenya Survey Form and Nomenclature

A. Point and Surveyor Identification
002 (01) District code — 17591 (02) Point code

B. Data on the observation
002 (03) Surveyor code — 15072013 (04) Date (dd/mm/yyyy) — 1230 (05) Time (hh:mm)

Distance of observation m: 0 (06) — Direction of observation (07): NW N NE / W E / SW S SE

GPS Waypoint *(Garmin Waypoint number)* 059 (08)

When the distance measured by the GPS is MORE THAN 30m the point was not reached.
Why? *(answer only if 06 is more than 30m)* permanents impediments N/A (09) or temporary impediments N/A (10)
Description of the type of impediment: N/A

Was the point observed? Yes No (11) *(a point is not observed if the exact land cover classification is impossible. In case of point NOT observed, provide a detailed explanation in the remarks)*

C. Data on land covers in and around the point
F02 (12) LCM code — Permanent Grassland without trees/shrubs (13) LCM Description — 100 (14) LCM %
(LCS - secondary land cover in case of association)
(15) LCS1 code — (16) LCS1 Description — (17) LCS1 %
(18) LCS2 code — (19) LCS2 Description — (20) LCS2 %

D. Data on the crop in the plot
Is the crop standing? N/A (21) or Was the crop already harvested? N/A (22) Estimated date of sowing: N/A (23)

E. Remarks: *(if more space is needed, please write on the back of the page)*
- within a homestead.

Figure 15: Scanned filled field forms for point 13304 and 17591 in Kakamega District.

3. DEIMOS and Landsat 8 image classification

The goal of this activity is to use the DEIMOS or Landsat 8 data to perform crop mapping in the region of Kakamega.

3.1. DEIMOS and Landsat 8 image pre-processing

The initial plan was to use the DEIMOS data, from DEIMOS-1 satellite (member of Disaster Monitoring Constellation) to carry out the crop mapping in the region of Kakamega. However, the DEIMOS acquisition coincided with the rainy season, so that the chance to obtain a cloud free image is very low. Therefore, the Landsat 8 images were use as replacement as the acquisition of the data by NASA was more frequent.

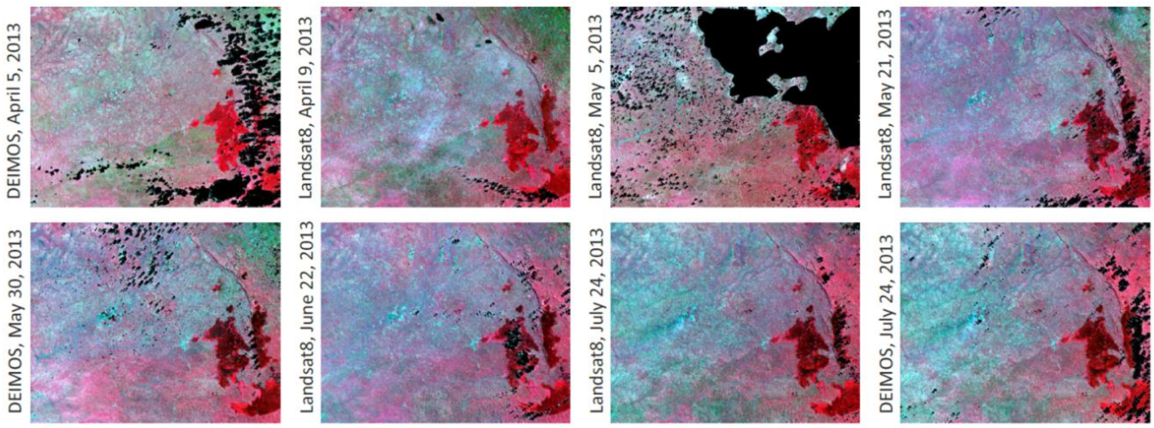

Figure 16: Overview on the acquired and pre-processed DEIMOS and Landsat8 data.

3.2. Ground truth data

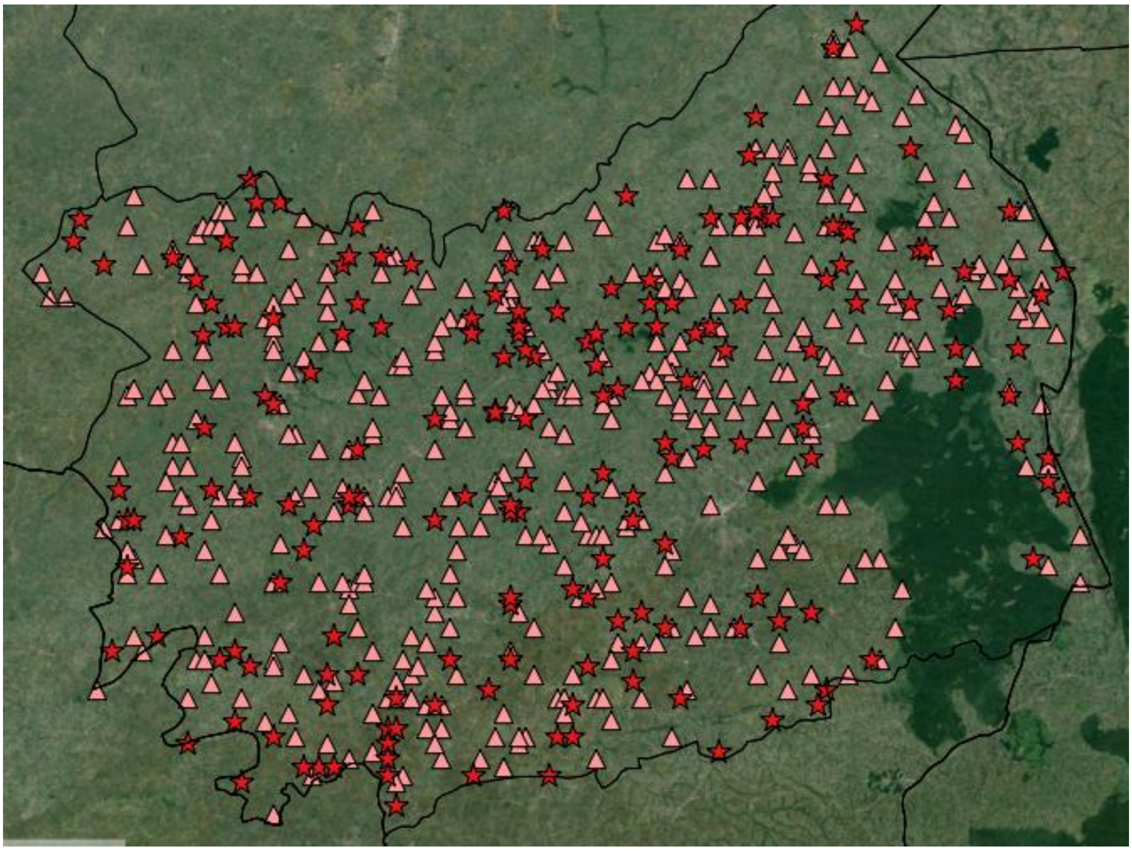

Figure 17: Point sample collected during the ground survey in June-July/2013. These data were used as reference data in the classification exercises

The ground truth data were collected in the district of Kakamega as described in the previous section (Figure 17). In total 347 points with their geographic positions and their agricultural attributes were registered 50% of these points was used for the calibration or training and 50% of points were included for validation of classification. Figure 18 displays the spectral features of different training classes.

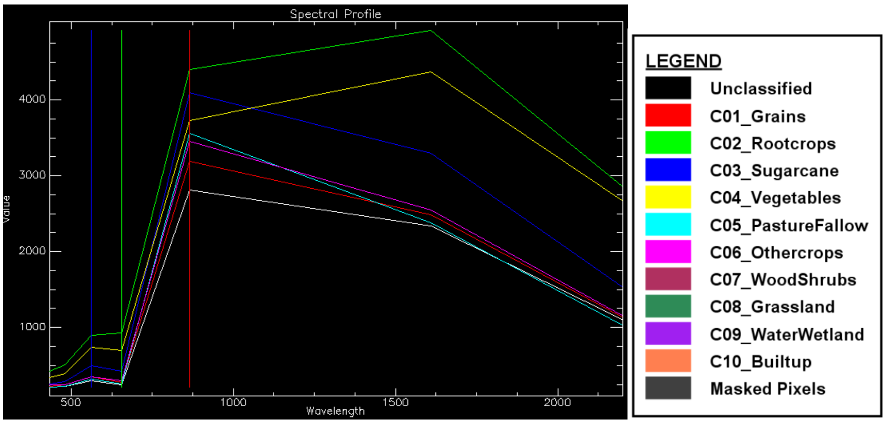

Figure 18: Analysis of the spectral profiles of the different training classes

3.3. Image classification results

Figure 19 displays the classification results of using two classifiers: k-means and maximum likelihood classifiers.

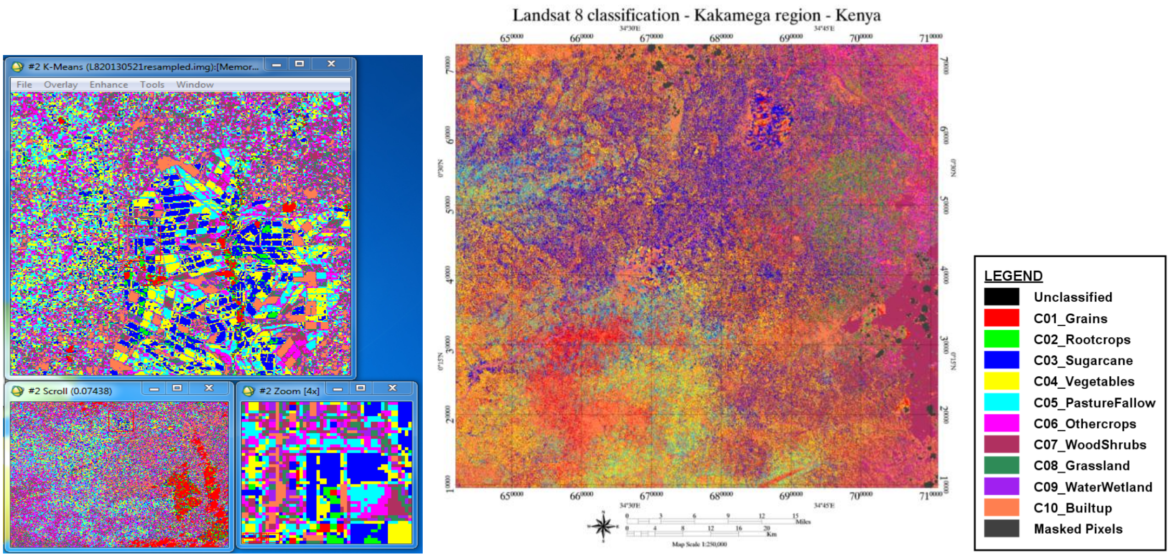

Figure 19: Classification results of Kakamega districts using k-means classifer (left) and Maximul likelihood classifier (right).

4. Conclusions

An estimation of crop areas through field survey is not practicable for a large area at the national level. Problems are mainly found at logistical and practical level. Many accesses to the sampling points are impassable due to the poorly restored roads as well as rough and rock terrains (Figure 20), or even due to thick plantation of sugarcanes.

Figure 20: the rough and rocky terrain in Kenya lead to a crop area assessment through field survey difficult and inefficient.

In this situation, although local authorities provide their permission to the collection of ground data, implementation of a systematic collection cannot be envisaged due to the general environmental or infrastructural conditions. In this case, a nearly pure remote sensing approach is recommended and the role of fieldwork is limited to collect ground truth data for training image classification and a coarse accuracy assessment. Accuracy requirements are more likely to be reached in this type of situations combining coverage of moderate resolution images with a sample of high-resolution images.

In the case of Kenya, an operational system for monitoring the crop areas in Kenya can be established through a combined use of MODIS and Landsat 8 OLI data. Especially, the approach can be improved in terms of accuracy once the spectral profiles from OLI dataset for targeted crops are established. Furthermore, in order to take advantage of phenological information of crops, an acquisition of multi-temporal image datasets is recommended. For this purpose, an enlargement of image data sources needs to be examined. Imagery generated by other high-resolution sensors can be combined with those that we used in this research to achieve an improved assessment for crop areas in the country.