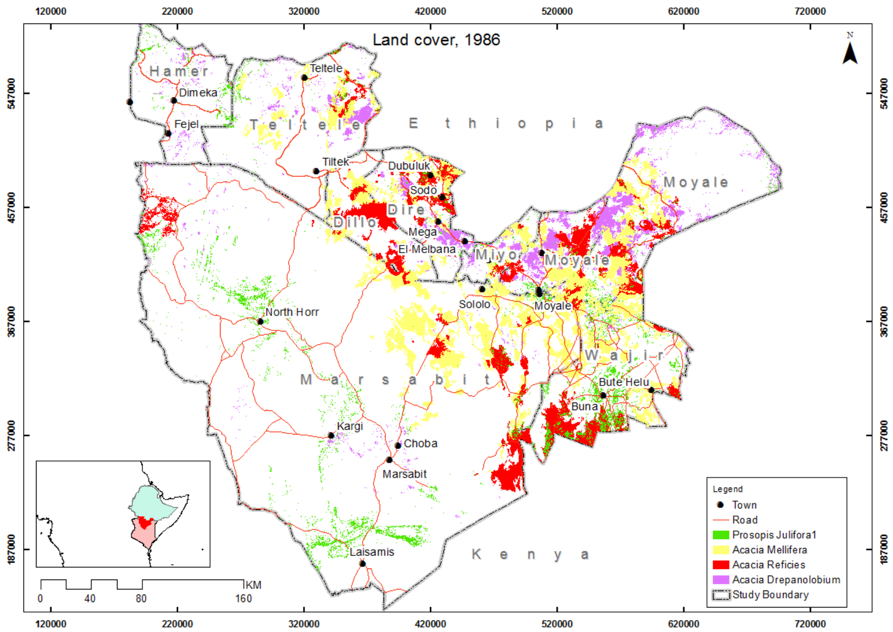
# Regional Pastoral Livelihoods Resilience Project

# (RPLRP)

## Land Cover and Change Analysis of Cross-border Areas around Southern Ethiopia & Northern Kenya




## Draft Report

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## Table of Contents

## List of Figures and Maps

## List of Tables

## List of Acronyms

EMA: Ethiopian Mapping Agency

ETM: Enhanced Thematic Mapper

EVI: Enhanced Vegetation Index

FAO: Food and Agriculture Organization

GIS: Geographic information System

GPS: Global Positioning System

ICPAC: IGAD climatic Prediction and Application Center

ICPALD: IGAD center for Pastoral Areas and Livestock Development

IGAD: Inter Governmental Authority on Development

LCCS: Land Cover Classification System

LiDAR: Light Detection and Ranging

MESA: Monitoring of Environment for security in Africa

NDVI: Normalized Difference Vegetation Index

RCMRD: Regional center for Mapping of Resource for Development

RFE: Rainfall Estimate

RPLRP: Regional Pastoral Livelihood Resilience Project

SAVI: Soil Adjusted Vegetation Index

SRTM: Shuttle Radar Topographic Mission

USGS: United States Geological Survey

## Definition of Key terms

**Land cover/ Land use change:** refers to changes in the attributes of a part of the earth's land surface and the immediate sub-surface.

**Image Classification:** defined as the process of extracting differentiated classes or themes from remotely sensed satellite data.

**Geodatabase:** is the native data structure for ArcGIS and is the primary data format used for editing and data management. While ArcGIS works with geographic information in numerous geographic information system (GIS) file formats, it is designed to work with and leverage the capabilities of the geodatabase.

**Geographic information system**: is a system designed to capture, store, manipulate, analyze, manage and present spatial or geographic data.

**Spectral signature:** is the difference in the reflectance or emittance characteristics with respect to wave length.

**Image Segmentation:** is a process of partitioning a digital image in to multiple sets of pixels.

## Executive Summary

Multi temporal satellite images and remote sensing and GIS based techniques were used to map land cover, and analysis of land cover change, status of rangelands, and spatial distribution of invasive woody species. . The study areas are largely fall in the pastoralist dominated arid and semi-arid (ASAL) areas of southern Ethiopia and Northern Kenya. Landsat TM, ETM and Landsat 8(OLI) of 1986, 2000 and 2016 were used for land cover mapping and change analysis. . Spatial distribution of four selected invasive woody species were mapped using 2016 sentinel-2 Satellite image combined with the topo climatic factors such as NDVI, altitude and rainfall. All the images were acquired during dry season, mainly January.

Object based classification method was used by ecognition software in both cases. Nearest neighborhood classifier algorithm was used to categorize the land cover classes. At the beginning, FAO land cover classification legend was followed. At later stage, some of the classes were merged, relevant to the study objective, and shorter version classifications legend produced. Sample land cover features and invasive species cover were collected from the study area during the mapping activity, and the information was used to improve quality of land cover classification and for assessment of classification accuracy.

The following are key findings depicted in this report:

- ✓ The study area includes three Regional States in Ethiopia (Hamaer Woreda from SNNP; five woredas (Dire, Dilo, Miyo, Moyale & Teltelefrom Borana Zone of Oromia; and Moyale woreda from Ethio-Somali; and two counties in Kenya (The whole of Marsabit and part of Wajir). In addition, Dasench and Nyangatom Woredas in South Omo (SNNP) of Ethiopia were consider for analysis of spatial distribution of invasive woody plant species and current land cover mapping;
- ✓ The total size of the study area is ~123970 km$^2$:  43584 km$^2$ in Ethiopia and 80386 km$^2$ in Kenya;
- ✓ Major land cover changes were observed mainly in Closed Shrubland that its area of cover increase from 13602 km$^2$ to 49046 km$^2$ (increased by more than triple in 30 years) between 1986 and 2017. In the same period, the land cover of Grassland decreased from 20% to 10%;Four major invasive woody species were identified and their current distribution were mapped for the project area. *Acacia (Vachellia) Drepanolobium*, *A (Vachellia) Mellifera*, *A (Senegalia) Reficiens* and *Prosopis. Juliflora* were found to be the dominant invasive woody species in the study areas. In general, *A. Drepanolobium* and *A. Mellifera* are widely spread in Borena rangelands and *A. Reficiens* is widely spread in Marsabit County. *P. Juliflora* is more common in Wajir county of Kenya and, Ngangatom and Dasench woredas of Ethiopia;

- ✓ In general an estimated area of 25876 sq km is covered by the four invasive woody species. *A.mellifera* found to be the most distributed invasive tree with area coverage of 12% and 7% in Ethiopia and Kenya respectively. *P. juliflora* is least distributed with area coverage of 2% in Ethiopia. While A. drepanolobium found to be least distributed in Kenya with area coverage of 0.51%;
- ✓ Rangeland degradation status is categorized in to five classes depending on level of degradation, namely Very high, High, Moderate, Low and Very low. In general 34% of cross border areas in Ethiopia and 18% in Kenya fall under Very high degradation status.

## 1. Introduction

The pastoralists in the cross border areas of Ethiopia and Kenya are suffering from rangeland degradation due to bush encroachment, grazing pressure and soil erosion caused by vegetation cover loss. In some areas tree cutting for fuelwood, land clearing and Charcoal burning have severely affected the ecosystems by reducing biomass and indigenous trees in the landscape that further accelerate land degradation.

Land cover (LC) can be considered a geographically explicit feature that can be used in different disciplines (geography, ecology, geology, forestry, land policy and planning etc.) as a geographical reference (e.g. for land-use, climatic or ecological studies). In modern geographic databases, due to its relatively easy specialization, LC has become a sort of “boundary object” between different disciplines. This development, on the one hand enhances the value of the LC information, but on the other hand enlarges the base of potential users, posing new challenges for its harmonization and consistent use. New LC information is constantly being produced.

The mapping of land cover and changes of a wide area throughout a given period of time is made easy through remote sensing and GIS techniques. Freely available earth observation data has been contributing to support the decision-making process on natural resource management. Medium resolution Satellite sensor designed to monitor natural resources such as Landsat and Sentine-2 are widely used in developing countries with minimum budget allocation and reasonable product quality and accuracy.

The Intergovernmental Authority on Development (IGAD) through the World Bank funded Regional Pastoral Livelihoods Resilience Project (RPLRP) has hired consultant to map current land cover, temporal land cover change, extent of rangeland degradation and distribution of woody invasive species in the cross-border areas of Ethiopia and Kenya. The aim of the mapping exercise is to use as input for the effort to build drought resilience livelihoods in the pastoral communities of cross-border areas.

In order to carry out the assignment, Landsat satellite images of 30 meter resolution from three epochs (1986, 2000 and 2016) were used. Additionally, Sentinel-2 images with resolution of 10 meter was used to map spatial distribution of four very common invasive woody plant species in the study area (Kenya and Ethiopia).

In the following consecutive sections of this report, I will present objective of the assignment, scope and limitations, methodologies employed, results obtained and final conclusion.

## 2. Objective of the study

The overall objective of the assignment is to support sustainable management of cross-border rangelands through land cover change analysis, and identifying and mapping areas for priority intervention by the RPLRP in the two countries.

The Specific objectives of the assignment are: -

- ✓ Produce overall land use map of the IGAD Cluster two, following the FAO land use classification, by using available recent images;
- ✓ Conduct temporal analysis of land cover change of same by taking three reference epochs (1980’s, 2000, and 2016);
- ✓ Identify priority cross-border rangelands in terms of degradation – considering invasive species and land use change; and
- ✓ Identify and map spatial distribution of major invasive woody plant species in the cross-border areas and cross-border rangelands of the IGAD Cluster two.

## 3. Scope and Limitation of the Study

The study was carried out only in part of the pastoral communities in the southern Ethiopia and northern Kenya by using cross-border and administrative boundary as criteria. However, rangeland and pastoralist mobility in Kenya and Ethiopia cover wide area and thus the pastoralists move beyond the study area boundary, in both countries. During the images acquisition, the plan was to use a wet season and dry season images for each year, but later it was found that the quality of image in the wet season is very cloudy and not feasible to use in the analysis. Thus time series NDVI was integrated in the analysis. In addition, analysis of sentinel 2 image was very challenging as it requires computer with high speed processer. So, the classification of the sentinel 2 satellite images were conducted scene by scene due to difficulty to mosaic the images as on big image.. Thus the process took longer time than expected. Furthermore the field data collection was not included information about tree/species density at plot level especially for invasive woody plants and thus the report does not include about invasive plant density for the mapped area. The field sample data collection in Moyale werda in Ethiopian Somali region was not carried out due to some insecurity and accessibility issues. Therefore, information was gathered through semi structured interview with the RPLRP staff at Moyale town. Dasench and Ngangatom werdas of Ethiopia were added to the mapping exercise during the field work by the request from Ethiopian RPLRP project. Thus, the report considers only mapping of the current land cover and spatial distribution of invasive woody species, by using Sentinel 2 satellite image acquired in 2016.

## 4. Methodology

### *4.1. Description of the Study Area*

The study area is geographically located at 36°9’ - 40° 49' East and 1° 16' - 5° 30' North. The area has an altitude range from 280 to 2473 meter above sea level (m.a.s.l) The area falls within two countries: Ethiopia and Kenya. In Ethiopia three regional States are represented: six woredas (Dire, Dilo, Miyo, Moyale, and Teltele) from Oromia, one Wereda (Hammer) from Southern Nations Nationalities and Peoples (SNNP) and one woreda (Moyale) from Somali-Ethiopia. In Kenya two counties are included: the whole of Marsabit County and part of Wajir County. Additionally two Woredas from SNNP (South Omo) of Ethiopia were included only for land cover and invasive woody species mapping.

Arid and semi-arid land (ASAL) constitute about 80% of Kenya’s landmass, and the area receives an annual average rainfall of between 200 and 600mm and annual temperatures range from 23°C to 34°C. Semi-arid areas are located in higher altitude (900 to 1800m) as compared to arid areas, experience an average annual rainfall upto 600mm, and are slightly cooler. The semi-arid, arid and very arid regions of Kenya also harbor the majority of Kenya's wildlife areas, and are consequently vital to the country's economy. The mean annual rainfall is about 500 mm in Ethiopian part of the study area, and the mean annual temperature is about 24 $^{o}$C with a mean maximum of 28 $^{o}$C and mean minimum of 17 $^{o}$C.

The rainfall of the study area is bimodal with long rains that occur between March and May and the short rains are (usually between September and October). The long rains account for 60% of the total annual rainfall, while the short rains contribute about 30% (Terefe et al, 2011).

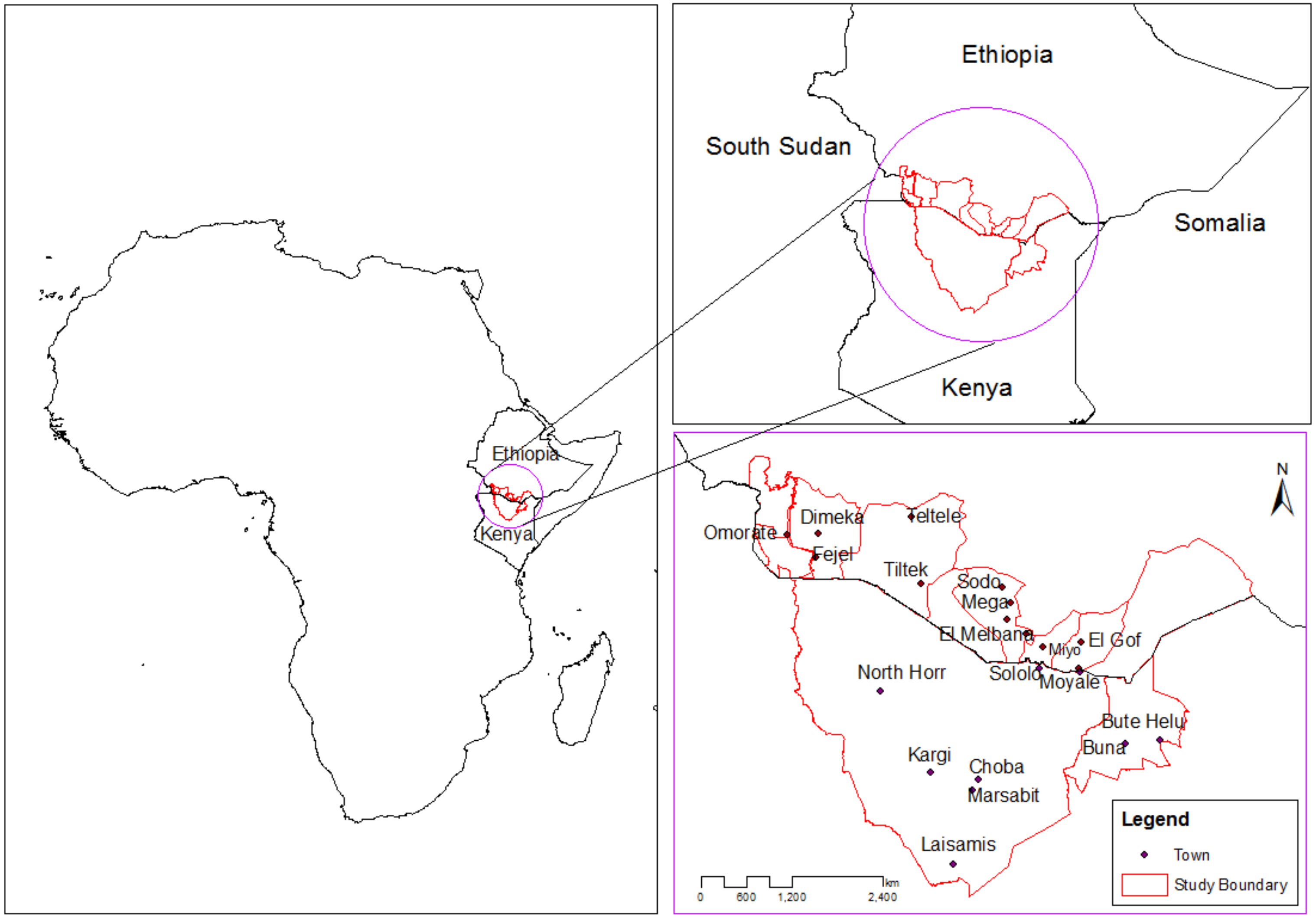


**Figure 1: Location Map of the Study Area**

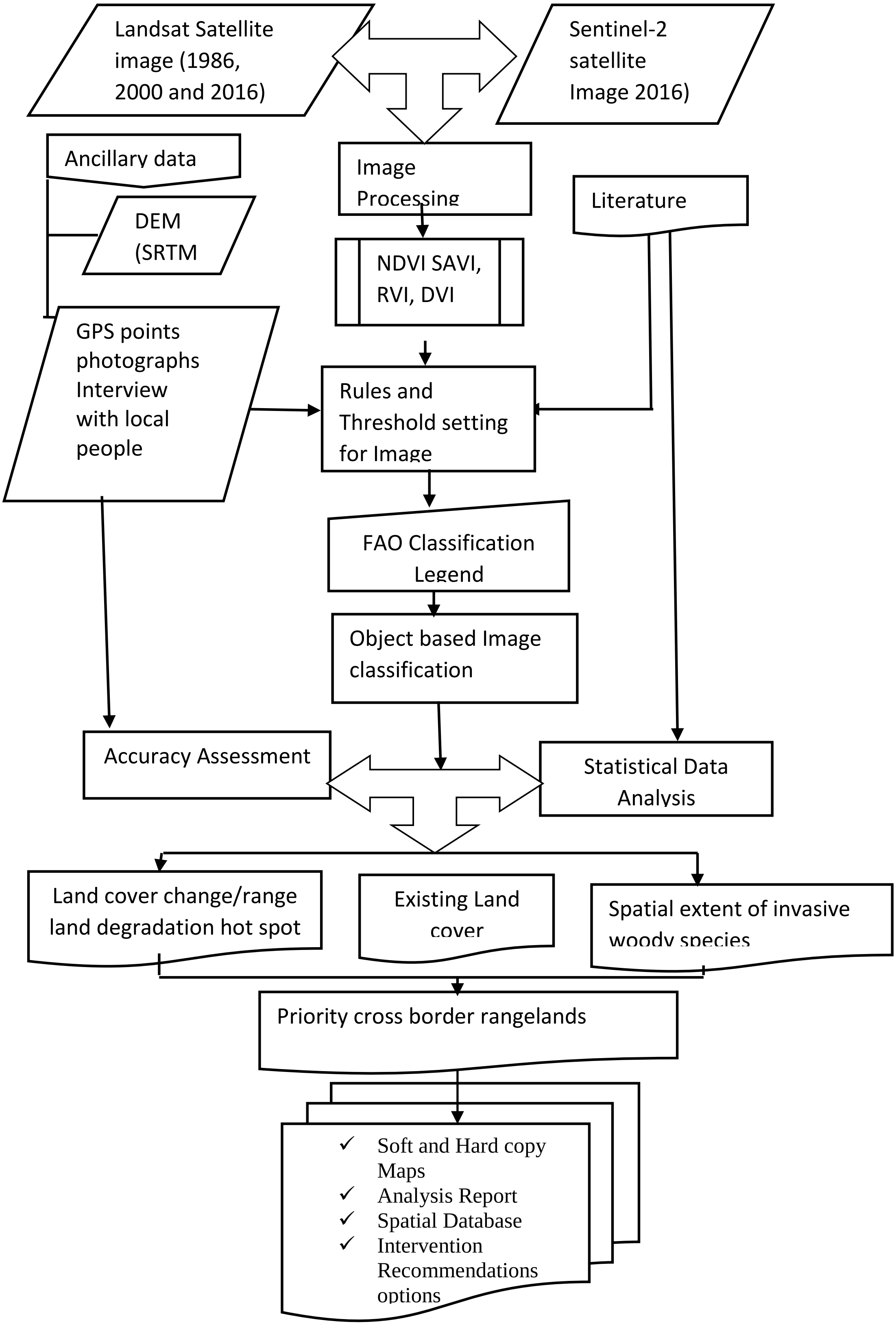


Figure 2: Flow chart of the overall mapping process

### 4.2. Data Collection

#### 4.2.1 Satellite Image Acquisition

Landsat satellite images from 1986, 2000, and 2016 with spatial resolution of 30m taken in January were acquired from USGS archive. January is dry season in the area and image from dry season helps to avoid overestimation of vegetation cover that might arise due to high reflectance from seasonal herbaceous vegetation. In addition, Sentinel-2 satellite images of January 2016 with a resolution of 10m was acquired from the same archive.

Previously produced land cover maps of the study area were also collected from different sources to widen the knowledge about the study area and in order to improve accuracy of land cover classification.

#### 4.2.2 Image Preparation

The geographic teritory of the study area was provided to the consultant by the IGAD RPLRP at the beginning of the assignment. Mosaic was prepared by combining different satalite image scenes covering the study area. All, satellite image scenes contained in to the provided study area boundary were selected (see Annex 1 & 2). Layer stacking of bands was carried out using bands that are used to easily differentiate different vegetations or land cover. For Landsat 5 and 7, band numbers 4, 3, and 2 were selected and for Landsat 8,  band number 5, and 3 were used. For sentinel 2 satellite images band composition was prepared from 8, 4, and 3. The band numbers represent the near infrared(NIR), red and green reflectance of the electromagnetic spectrum (EMS).

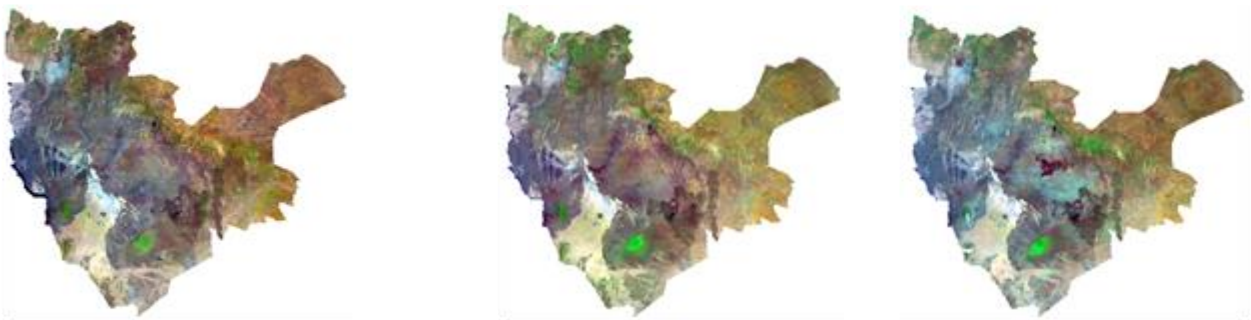

Figure 3: Landsat Image (Mosaic of bands 5, 7 and 8) of the three studied epoch (1986, 2000 7 2016)

#### 4.2.3 Image Processing

Images acquired from archive then taken through various image processing stages such as haze reduction, histogram equalization, contrast stretching to come up with a good quality image for image interpretation and classification.

### 4.3.4 Field Sample Point Collection

ArcMap software was used to randomly generate 1500 sample points from unsupervised classification map prepared prior to the field work. Some criteria were developed to down size the number of random points to 970. Then from the 970 random field samples, 224 were visited during the field work. Then qualitative data were collected from each land use land cover feature that were prepared based on FAO land cover classification system (see Annex 3). The following criteria were used to down size the number of sample points during the sampling design (Fig 4).

- ✓ Distance from the road to be 5km
- ✓ Distance from the town or the nearby village to be 15km
- ✓ At least 10 sample points should be visited per day.

The remaining samples were validated using high resolution imagery from Google earth during the accuracy assessment process. The distance between the samples was set to be ~1km. During visit to the selected sample points, the following qualitative data were collected from each plot: land cover type, general land form, vegetation type, life form, dominant vegetation, height of the vegetation, and estimates of percentage of cover.

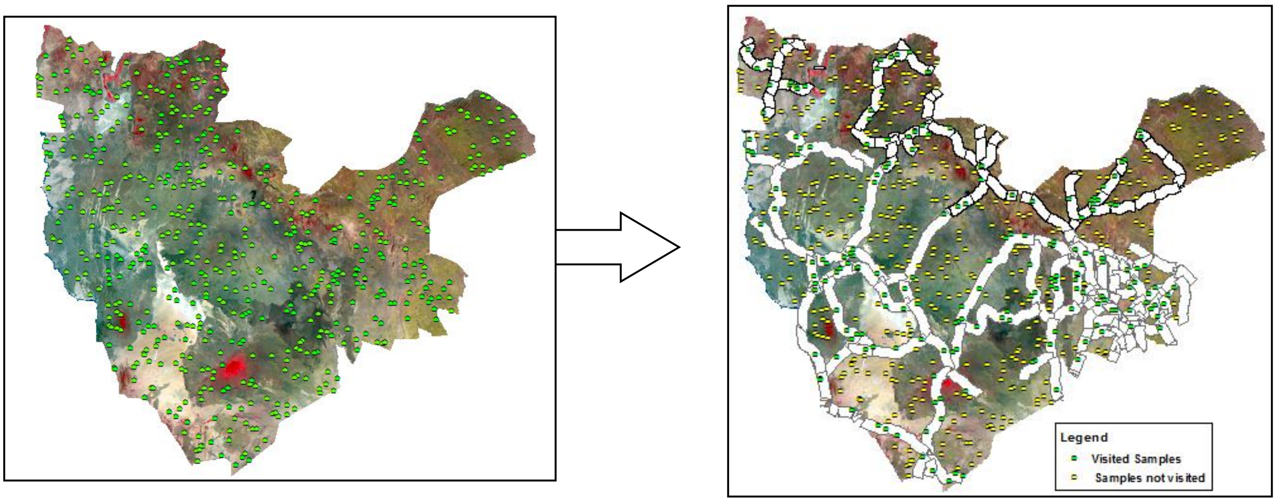


**Figure 4: Sample Point Distribution: the dots in the left picture indicates random point and the picture in in the right indicates sampled random points**

RPLRP project staff in the study area were consulted in order to identify areas where invasive woody species are widely distributed. Therefore, land cover samples of invasive species were collected from specific sites under the guidance of local RPLRP staff. The four species were identified to local and scientific name with the help of rangeland experts and the local residents.

**Figure 5: Field data collection photographs In Wajir county**

### 4.2.5 Land Cover Mapping

Land cover mapping was carried out by classifying the satellite image in to meaningful features. Land cover classification is a process of categorizing similar or nearly similar features in to a specific entity based on their characteristics including spectral reflectance to a specific range of wavelength, this can be done using the processing and interpretation of satellite image using various algorithms developed so far. Among these algorithms and methods, pixel based and object based classifications are widely used.

Pixel based classification only accounts a pixel value of a given phenomenon in satellite image. This method always has drawback in classifying similar object as different or different object as similar as it only accounts the pixel value. For example, reflectance from herbaceous vegetation and trees seems similar in wet season. Also, the shadow of an object has similar pixel value as that of water body without sediments. In contrary, object based classification doesn't only account the pixel value of the phenomena but also their shape, pattern and frequency of occurrence, due to this it always results a better accuracy than pixel based classification.

eCognition was used to segment and classify land cover classes based on the object based classification method. eCognition is able to utilize size, shape, color and contextual information in the classification process, and provides a way to integrate remotely sensed data and GIS (Benz *et al* 2004). An overview of the procedures performed by eCognition is discussed below. Both the Landsat and Sentinel-2 images were added to eCognition turn by turn for segmentation process and more weight was given for the near infrared band during the segmentation. The images were segmented with a constant "composition of homogeneity criterion" and the "scale parameter" set 50. The scale parameter and the composition of homogeneity criterion define a threshold for the maximum change in heterogeneity that may occur when two object-primitives are merged, and any merging that exceeds the defined level terminates the segmentation process. A larger scale parameter results in a smaller number of object-primitives.

The default settings for the "composition of homogeneity criterion" were used, that is color 0.9, shape factor 0.1, with shape factor divided into compactness 0.5 and smoothness 0.5.

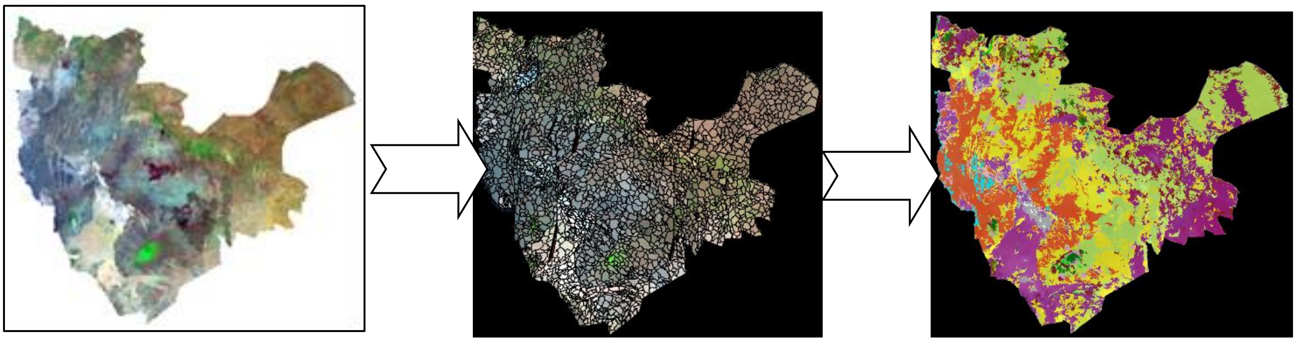

**Figure 6: Sample output** from **segmentation in eCognition**

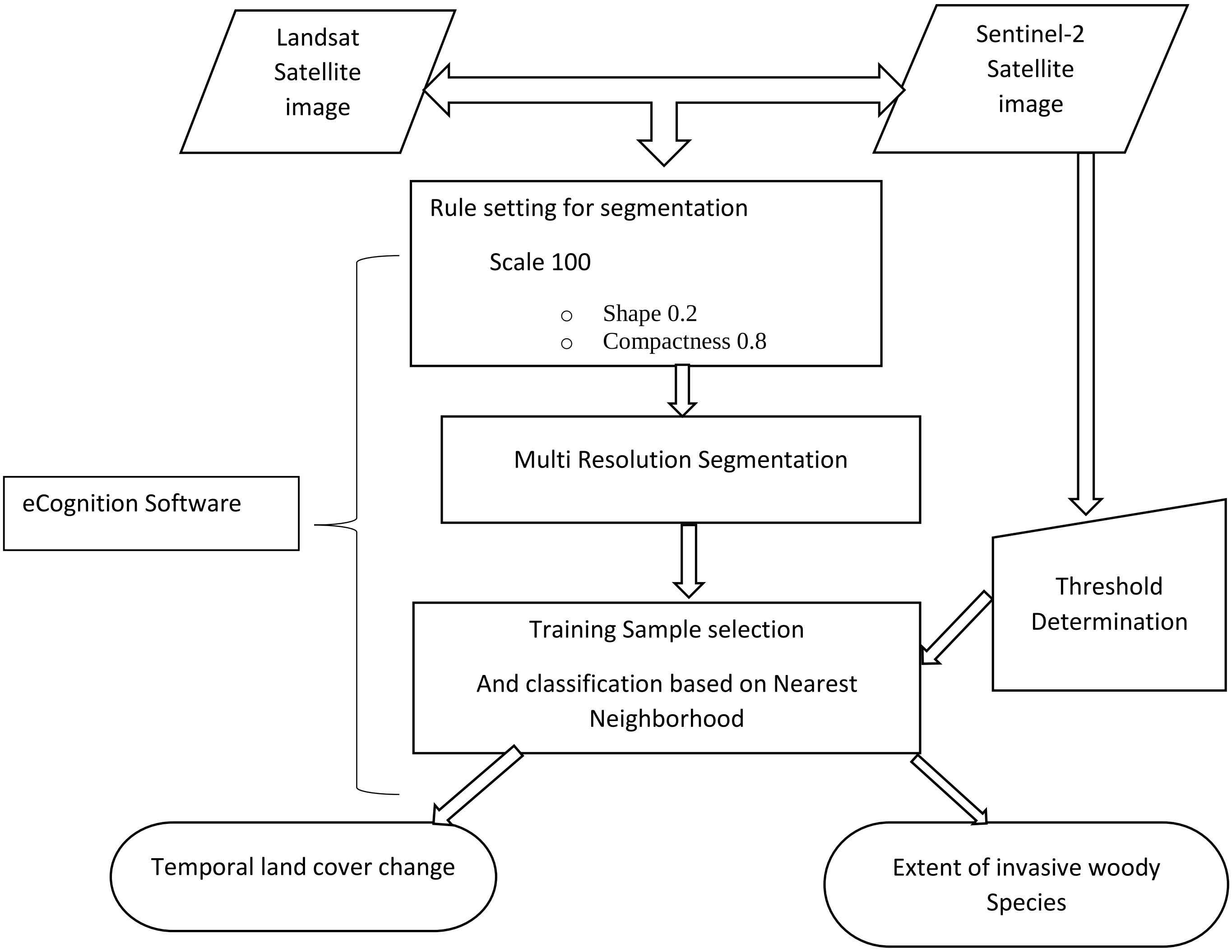


**Figure 7: Image segmentation process**

### 4.2.6 Assessment of Accuracy

The accuracy assessment of the obtained classification was carried out. About 224 points were distributed randomly within the classification image. Results of accuracy assessment in the form of error matrix table, with overall accuracy, is presented. (See Annex 5).

### 4.2.7 Land Cover Change Analysis – Change Detection

For performing land use/cover change detection, a post-classification detection method was employed. Land cover comparison from 1986 to 2016 was used to produce change information using the polygon layer generated from eCognition and thus, interpret the changes more efficiently taking advantage of the ‘‘-from, -to’’ information. Classified images were compared using cross-tabulation matrix to determine qualitative and quantitative aspects of the changes. A change matrix (Weng, 2001) was produced with the help of ArcGIS software. Area coverage of the overall land use/cover changes as well as gains and losses in each category among 1986, 2000 and 2016 were then compiled.

$A = \frac{\mathrm{F-I}}{I}$, …………………………………………….…. a (K M Kafi et al, 2014)

$K = F - 1$……………………………………………..………. b (K M Kafi et al, 2014)

Where K = Magnitude of change

A = Percentage of change

F = First date

I = Reference date

### 4.2.8 Distribution of Invasive Woody Species

Invasive plants are naturalized plants that produce large number of offspring, have the ability for long distance dispersal, and thus have a potential to spread over a considerable area (Theodros et al. 2016)

A multi criteria GIS layers were prepared to identify the invasive woody species in ArcGIS software. Then four different parameters (Table 1) were overlaid to identify the spatial distribution of invasive species (Ragavan et al 2015).

The mean SAVI value of the invasive species were generated based on the field samples. Samples were collected for *Acaica drepanolobium*, *A. Mellifera*, *A. reficiens* and *Prosopis juliflora* (See Annex 4). In addition, topo climatic factors (altitude and rainfall) of each species were found from previous similar studies and the values were derived from SRTM and rainfall data respectively.

**Table 1: Invasive Species Mapping Parameters**

| S. N | Species Name | English Name | Mean NDVI threshold | Altitude m.a.s.l. l | Mean Rainfall | Source |
|---|---|---|---|---|---|---|
| 1 | *Acacia drepanolobium* | Whistling thorn | 0.12-0.15 | 1000-1500 | 500 mm | Angassa and Oba, 2007 |
| 2 | *Acacia Mellifera* | Black thorn | 0.1019-0.1601 | 1000-1400 | 400-800 | Wiknes etal,1995 |
| 3 | *Acacia reficiens* | False umbrella thorn | 0.098-0.1367 | 500-1000 | 400-800 | Web source |
| 4 | *Prosopis Julifora* | mesquite | | 500-1700 m | 100mm-800 mm | Kazmi *et al*., 2010 |

The limitation of such method is that due to the coarse spatial resolution of both the climatic and satellite data, the species might not be differentiated at the desired accuracy, especially if the species has similar phenological stage. So, this method only uses the proxy indicator of the probability of presence of invasive species in the area.

### 4.2.9 Rangeland Degradation Indicator Development

In order to identify status of rangeland degradation, two main factors were considered. The first one is degradation associated with bush encroachment (closed Shrubland expansion), expansion of bare areas, and loss of woodlands, shrub lands and grassland that may impact pastures lands negatively. The second one is refers to rangeland degradation associated to distribution of the invasive species. In the first case the land cover maps (1986-2016) produced during classification were used to identify the factors in the first case. For the second method, the map produced for invasive species spatial distribution was used and the analysis is presented for each country in the form of table and graph. The map is prepared one for the whole study area.

Moreover a time series soil adjusted vegetation index (SAVI) is prepared and used to identify the degradation hotspots. SAVI is chosen because NDVI value is highly affected by soil reflectance in arid and semi-arid area (Huete, 1988).

$$SAVI = \frac{L+1(NIR-RED)}{(NIR+RED+L)}$$ ………………………………….C (Huete, 1988).

Where SAVI is, soil adjusted, vegetation index

NIR is Near Infra-Red

L is a canopy background adjustment factor (0.5)

### 4.2.10 Semi Structured Interview

In addition to the field data collection an informal and courtsy meeting was arranged with experts from Ethiopia and Kenya to identify priority invasive woody species. . During the meeting a semi-structured interview questionaire was administred as a discussion guide (See Annex 6)

### 4.2.11 Literature Review

Published and unpublished materials on land cover and land cover change of the study area were reviewed. The literature review also include how remote sensing has been applied in areas of invasive species, and rangeland degradation mapping.

## *4.3.* Classification legend preparation

To determine the legend for the land cover classification, the LCCS 2 software developed by FAO was used. The life form and an estimation of area cover percentage of a specific land cover feature among the coexisting land covers was used as a primary criterion during using the FAO tool. The tool is a comprehensive, standardized and a priori classification system. The classes in LCCS are predetermined, designed to meet specific user requirements, created for mapping exercises that are independent of the scale or means used to map (LCCS/FAO, 2005). It uses independent diagnostic criteria or classifiers, which allow correlation with existing classifications and legends. The classifiers are hierarchically arranged for high degree of geographical accuracy. The classification has two main phases; a Dichotomous Phase – with 8 major land cover types and a Modular–Hierarchical Phase that has a set of classifiers with their hierarchical arrangement tailored to the major land cover type. Initially, FAO land cover classification was followed and later the land cover classes were simplified by merging similar classes in order to fit to the objective of the assignment.

The challenges were seen preparing a classification legend for open shrub and open to sparse wood land as the classification doesn't represent exactly the context of the area. For example, sparse woodlands are existed in two forms in the study area: one is with secondary vegetation shrubs and herbs in the case of Hammer in Ethiopia and the other is on bare red soil in the case of Wajir and on the road from Marsabit to North Hor. Also, difficulties encountered to differentiate artificial and non-artificial water bodies. Similarly, the woodland near Teltele town was difficult to assign to a specific class.

The initial classification legend was prepared (See Annex 3). Table2 below shows the contextual definition of the aggregated land cover features from the initial classification. The definition is prepared from field observation and similar previous studies carried out in both Northern Kenya and southern Ethiopia

**Table 2: Contextual Definition of Land Cover Features**

| S. N | Land cover/use | Initial Classification | Contextual Definition/meaning |
|---|---|---|---|
| 1 | Closed woodland (CW) | *Closed woodland* | *this category refers to a dense vegetation with natural or plantation with Height greater than 5m and the canopy cover is 20-50% (Marsabit forest park, Hammer forest and Mega woodlands)* |
| 2 | Closed shrub (CS) | *Closed Shrubland* | *Mainly composed of thick invasive woody species which grow densely like A. mellifera, a. reficiens with tree height less (1- 5m) and the secondary vegetation are dwarf herbaceous constituent sometimes bare soil.* |
| 3 | Open to sparse shrub (OSS) | *Open Shrubland & Sparse Shrubland* | *Constituents of sparsely growing shrubs with grass and other herbaceous trees as a secondary vegetation and most of the trees height is similar to that of closed shrub. In some low lands like Chalabi there is now secondary vegetation and instead there is loose gravel, sand and soil underneath.* |
| 4 | Open to sparse woodland (OSW) | *Open woody vegetation & Sparse woody vegetation* | *Mostly species such as A. Tortolis, A. Comifora, and A. Sayal existing with other herbaceous and palatable shrubs with trees grow sparsely and height greater than 5m. sometimes the trees are growing on red soil, and sandy soil as seen in Wajir, Marsabit, Mega and Moyale* |
| 5 | Grassland (GRSS) | *Open Grassland & Closed Grassland* | *Consisting of savanna grasslands and dwarf shrubs with few trees mainly grass as a dominant species.* |
| 6 | Water body (WB) | *Artificial non-perennial water body*<br>*Natural perennial Marshlands/swamps* | *Consists of swamps, wetlands, artificial pond, lakes and rivers both perennial and seasonal in their nature.* |
| 7 | Agriculture and settlement (AS) | *Rain fed Agricultural land*<br>*Settlement (villages and towns)* | *composed of agricultural lands with rain fed and irrigation system and the village, town nearby* |
| 8 | Bare area (BA) | *Unconsolidated materials*<br>*Consolidated materials* | *areas with consolidated and unconsolidated earth material, in this category sandy desert, stony area are included (Chalbi and Chew Bahir, Teltele)* |

### *4.4 Method of Result Validation*

Two methods were applied to validate the overall output of the study. The first one is evaluating the GPS data collected from the field against the classification result from ecognition for map validation. The second method is by comparing the result with similar previous studies and existing maps. In addition, secondary data collected from each project areas were used as a validation tool for quantitative output.

### *4.5. Method of Data Analysis*

The vector layers from the object based classification were overlaid and the temporal changes were calculated from 1986 through 2016.The rangeland degradation, in terms of land use change and invasive woody species, was also analyzed by estimating the change in constituents of the rangeland such as woodland, Shrubland, grass land throughout the study period. The degradation status in terms of invasive woody species was calculated from extent of the invasive species map. The report is compiled for the whole project area, but rangeland degradation is presented by country.

### *4.6. Data Handling and Management*

All the generated spatial data (raster and vector) were stored in a file geo-database prepared in ESRI ARCGIS software. The spatial data were generated in the form of map and the descriptive and textual information were recorded in tables.

## Result and Discussion

### 5.1. Current Land Cover of the Study Area (2016)

Based on the classification result indicated in Table 3 below, about 40% of the study area is covered by Closed Shrubland followed by Open to Sparse Shrub and Woodland with coverage of 29% and 14% respectively. Agriculture and settlement, and water bodies together cover less than 1%. Bare land covers 5% and grassland accounts about 10% of the study area.

**Table 3 : Land cover Area, 2016**

| S. N | Land cover | Area $km^2$ | % |
|---|---|---|---|
| 1 | Agriculture and Settlement | 353 | |
| 2 | Bare Land | 6765 | 5 |
| 3 | Closed Woodland | 1245 | 1 |
| 4 | Closed Shrubland | 49046 | 40 |
| 5 | Grassland | 12597 | 10 |
| 6 | Open to Sparse Woodland | 17702 | 14 |
| 7 | Open to Sparse Shrubland | 36224 | 29 |
| 8 | Water Body | 38 | |
| | Total | 123970 | 100 |

### 5.1.1 Current Land Cover of the Study Area: Ethiopia

The land cover in Table 4 below depicts land cover features in part of the southern Ethiopia, the study area. From the analysis, rangeland of the southern Ethiopia is dominated by Closed Shrubland (51%), followed by Open to sparse woodland (26%), and Open to sparse Shrubland (11%). Agriculture and settlement covers small area (1%). The closed woodland is mainly located in Hammer Woreda and close to Mega town in Dire Woreda.

**Table 4: Land cover in 2016, Ethiopia part**

| S. N | Land cover | Area in km2 | Percent |
|---|---|---|---|
| 1 | Agriculture and Settlement | 233 | 1 |
| 2 | Bare Areas | 1565 | 4 |
| 3 | Closed Woodland | 554 | 1 |
| 4 | Closed Shrubland | 22327 | 51 |
| 5 | Grassland | 2831 | 6 |
| 6 | Open to Sparse Woodland | 11258 | 26 |
| 7 | Open to Sparse Shrubland | 4794 | 11 |
| 8 | Water Body | 22 | |
| | Total | 43584 | 100 |

### 5.1.2 Current Land Cover of Study Area: Kenya (2016)

The north Kenyan part of the study area includes Marsabit and part of Wajir Counties. Table 5 below depicts that Open to sparse Shrubland is the dominant land cover with area coverage of 39 % followed by Closed Shrubland (33%) and Grassland (12%). Water body covers very small area and Bare land constituents 7%; most of the bare land is from the Chalbi Desert due to the loose sand and gravel material widely seen in Mykoni, Karagi and North Hor localities.

**Table 5: Current Land cover of the study area, Kenya (2016)**

| S. N | Class name | Sq km | Percent |
|---|---|---|---|
| 1 | Agriculture and Settlement | 120 | |
| 2 | Bare Areas | 5266 | 7 |
| 3 | Closed Woodland | 691 | 1 |
| 4 | Closed Shrubland | 26719 | 33 |
| 5 | Grassland | 9700 | 12 |
| 6 | Open to Sparse Woodland | 6444 | 8 |
| 7 | Open to Sparse Shrubland | 31430 | 39 |
| 8 | Water Body | 16 | |
| | Total | 80386 | 100 |

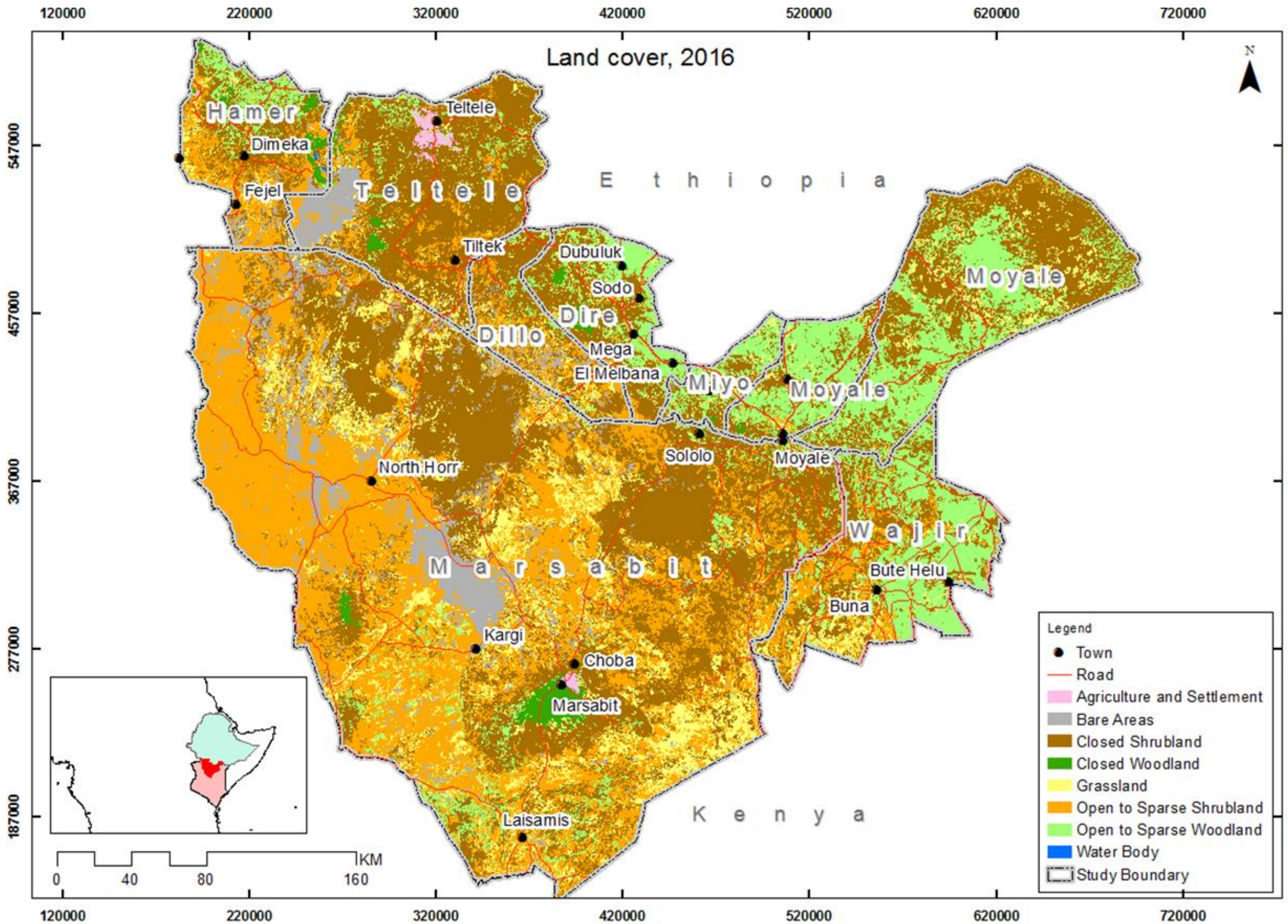


**Figure 8 Existing Land Cover Map, 2016**

## 5.2. Current Land Cover Analysis of Ngangatom and Dasench Weredas

Dasench and Ngangatom woredas are administratively located in the Southern Nation Nationalities and People Regional State (SNNPRS) of Ethiopia. The two woredas are located around Omo river where large-scale farming is under expansion by the government of Ethiopian. Earlier, the area is well known for irrigated cotton farming using Omo river. Figure 9 below shows the location of the two study woredas.

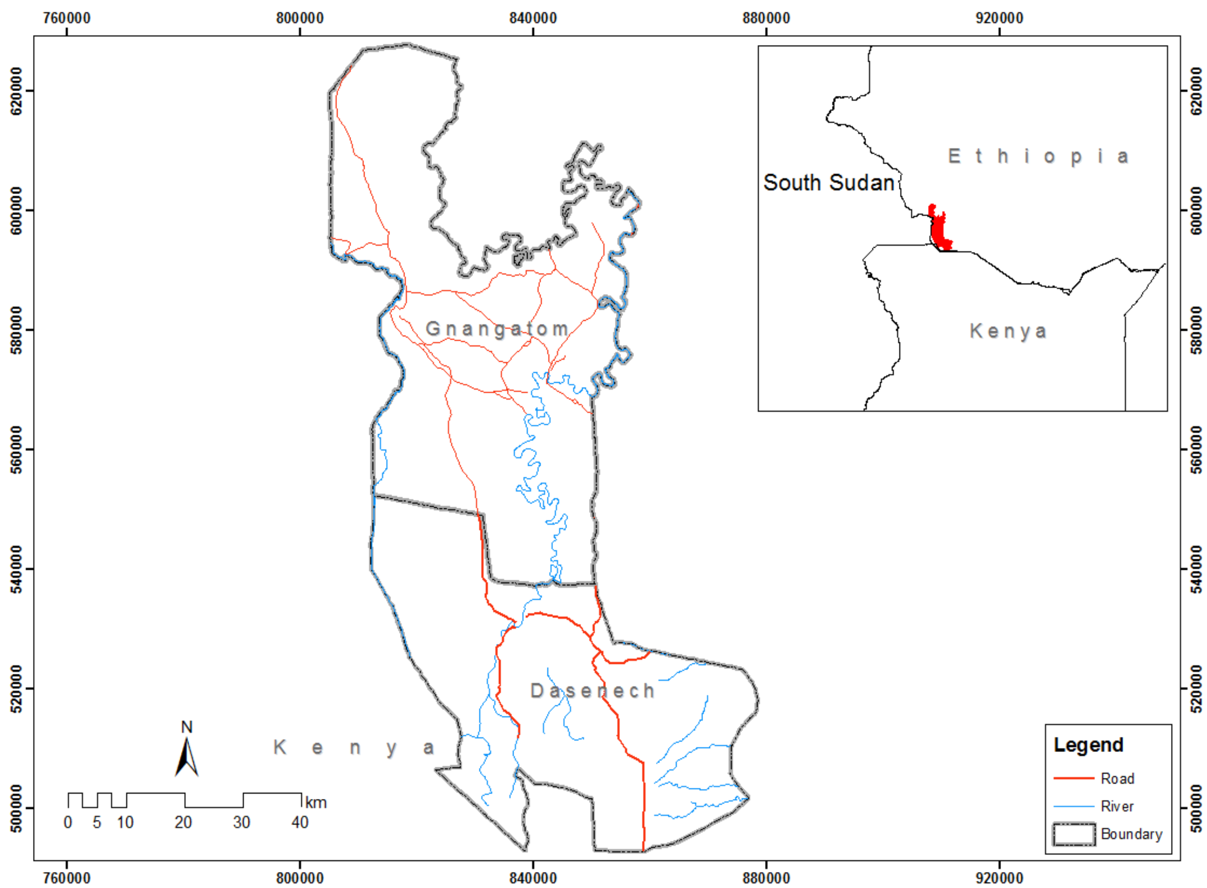


**Figure 9: Location map of Ngangatom and Dasench weredas**

Table 6 shows that the land cover type of Ngangatom and Dasench wereda. Sparse/Open woodland is dominating the land use that accounts for 38% of the total land cover. Open/ Sparse shrub is the second most distributed land cover and it accounts of 25% of the two woreda land cover followed by closed woodland that accounts 16%. The least distributed land cover is water body compared to other land covers. Agriculture and settlement accounts for about 4% while grassland covers about 9% of the total area.

**Table 6: Area coverage of current land cover in Ngangatom and Dasench wereda in Hectare (Ha)**

| S. N | Land cover | Two Woreda | | Dasench, Area | | Ngangatom, Area | |
|---|---|---|---|---|---|---|---|
| | | Ha | % | Ha | % | Ha | % |
| 1 | Agriculture and Settlement | 18400 | 4% | 9000 | 4 | 9400 | 4 |
| 2 | Bare land | 12200 | 3% | 9800 | 5 | 2400 | 1 |
| 3 | Closed scrubland | 12200 | 3% | 6600 | 3 | 5600 | 2 |
| 4 | Closed Woodland | 75600 | 16% | 33300 | 16 | 42300 | 16 |
| 5 | Grassland | 43700 | 9% | 17800 | 8 | 25900 | 10 |
| 6 | Open/ Sparse Shrub | 121000 | 25% | 77400 | 37 | 43600 | 16 |
| 7 | Open/Sparse woodland | 180500 | 38% | 47100 | 22 | 133400 | 50 |
| 8 | Water body | 11500 | 2% | 9300 | 4 | 2200 | 1 |
| | Total | 475100 | | 210300 | | 264800 | |

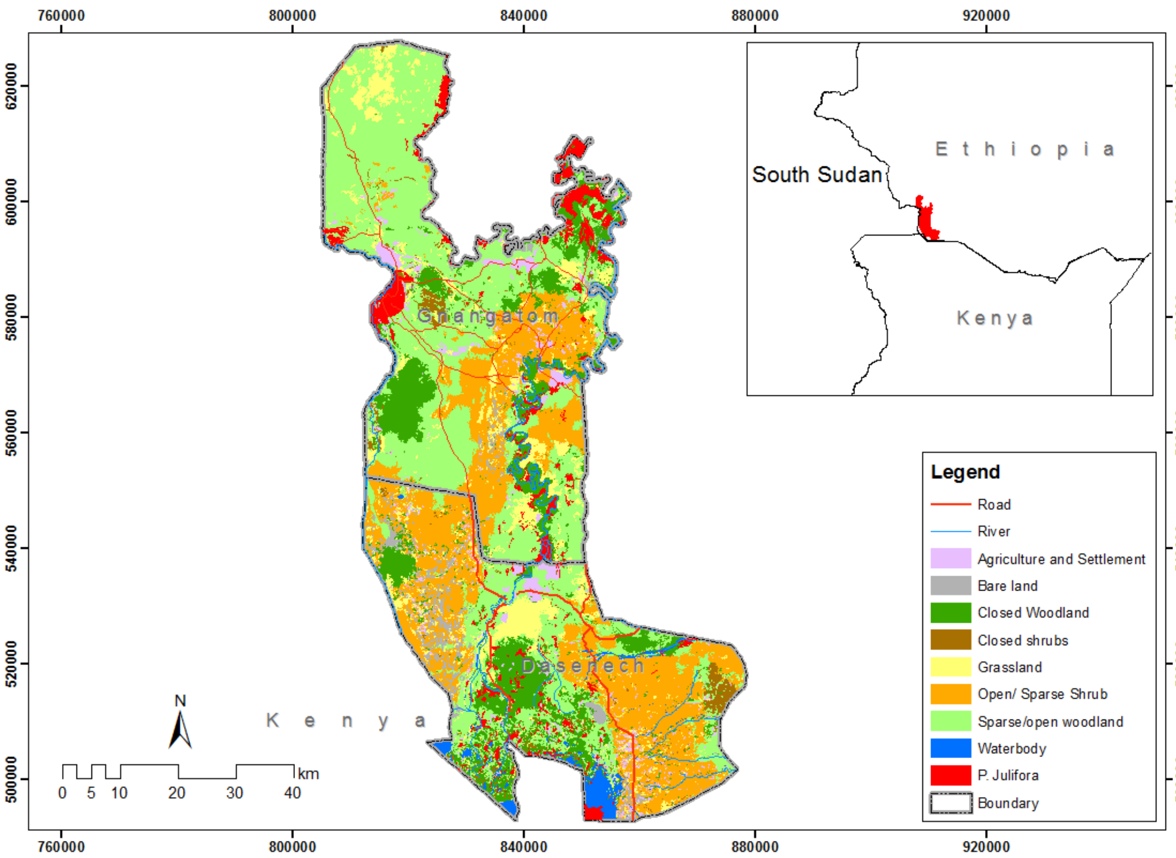


**Figure 80 Land cover Map of Ngangatom and Dasench (2016)**

### *5.3. Overall Land Cover Change (1986-2016)*

From the land cover analysis of 2016, it is found that closed Shrubland is dominant land cover type in the study area. Closed Shrubland is widely spread in Teltele, Dilo, Miyo and Dire Woredas of Ethiopia and Sololo, Moyale, Butte, and Buna localities in Kenya. This is also seen in Hammer, Dasench and Dire in the form of dwarf vegetation. The image analysis depict that Closed Shrubland in the study area was increased from 13600 $km^2$ to 49046 $km^2$ between 1986 and 2016 (Table 7), this is an increase of 260% or 35400 $km^2$. Such an increase in the Shrubland attributes to bush encroachment to grassland and other prime rangelands. Shrubland includes herbaceous plant with tree height less than 5 meter based on the contextual definition given in the Table 2. In the contrary, area under Grassland was decreased by about 48%, from 24371 $km^2$ to 12597 $km^2$. In localities such as Dire and Miyo, Grasslands have been affected by bush encroachment or expansion of invasive woody species such as *A. drepanolobium.* The Open sparse woodland with grass and shrubs as a secondary vegetation is also affected by the expansion of bushes. Similarly areas under Open/Sparse Shrubland also decreased by about 34% during same period (Table 7).

Water body also has been decreasing probably due to drying of streams and wetland. Even though, there is a practice of artificial earth dam construction, water is still scarce for livestock and human use in the area. In the other hand, areas agriculture and settlement are increased by about 100%. This indicate that some pastorals in the study area practice crop production. The image analysis also indicates that closed woodlands near Marsabit, Dire and Hammer are affected by the expansion of agriculture and settlement. The settlement expansion on the road from Bute to Moyale is also contributing to the decrease in area coverage of important woody species like *A. comifora* and *A. sayal* through charcoal making by the local people. The degradation in these species created open land that encourage local people to try small crop farming around their home. Table 7 below shows details of land cover change in the study area for three selected epochs, 1986, 2000 & 2016.

**Table 7: Land cover type of the study area during three epochs (1986, 2000 & 2016), in $Km^2$**

| Class name | 1986 | | 2000 | | 2016 | |
|---|---|---|---|---|---|---|
| | Area, $km^2$ | % | Area, $km^2$ | % | Area, $km^2$ | % |
| Agriculture and Settlement | 177 | | 277 | | 353 | |
| Bare land | 4708 | 4 | 4961 | 4 | 6765 | 5 |
| Closed Woodland | 2823 | 2 | 2198 | 2 | 1245 | 1 |
| Closed Shrubland | 13602 | 11 | 29318 | 24 | 49046 | 40 |
| Grassland | 24371 | 20 | 19008 | 15 | 12597 | 10 |
| Open/Sparse Woodland | 23326 | 19 | 20686 | 17 | 17702 | 14 |
| Open/Sparse Shrubland | 54895 | 44 | 47463 | 38 | 36224 | 29 |
| Water Body | 68 | | 59 | | 38 | |
| Total | 123970 | | 123970 | | 123970 | |

### 5.3.1 Land Cover Change of the Study Area in Ethiopia (1986-2016)

The land cover change for part of the project area that covers only Ethiopia is presented in Table 8 below. From 1986 to 2000, the highest increment was seen on closed shrub land, its contribution to land cover increased from 15% to 51%. While Grassland decreased from 18% down to only 6% between 1986 and 2016. This is mainly because of the bush encroachment by overtaking the grasslands. Area under Settlement and agriculture was also increased by more than 100%. In the same period, Open or sparse woodlands more or less remain same however tree cutting may already thinned the woodland. In general bush encroachment (Closed shrubland) into prime grazing areas is apparent from the analysis that it affected more than 2.2 million hectares.

**Table 8: Land cover Area coverage by year (Ethiopia)**

| S. N | Class name | 1986 | | 2000 | | 2016 | |
|---|---|---|---|---|---|---|---|
| | | Area, in Km$^2$ | % | Area, in Km$^2$ | % | Area, in Km$^2$ | % |
| 1 | Agriculture and Settlement | 90 | | 159 | | 233 | 1 |
| 2 | Bare Areas | 844 | 2 | 1374 | 3 | 1565 | 4 |
| 3 | Closed Woodland | 1998 | 5 | 1493 | 3 | 554 | 1 |
| 4 | Closed Shrubland | 6554 | 15 | 15021 | 34 | 22327 | 51 |
| 5 | Grassland | 7777 | 18 | 5938 | 14 | 2831 | 6 |
| 6 | Open/Sparse Woodland | 11841 | 27 | 11375 | 26 | 11258 | 26 |
| 6 | Open/Sparse Shrubland | 14434 | 33 | 8185 | 19 | 4794 | 11 |
| 8 | Water Body | 46 | | 39 | | 22 | |
| | Total | 43584 | | 43584 | | 43584 | |

### 5.3.2 Land Cover Change of the Study Area in Northern Kenya (1986-2016)

Table 9 below shows the land cover in km$^2$ for Kenya part of the study area. The image analysis revealed that land covered by closed shrub was increased from 9% to 33% (from 7048 Km$^2$ to 26719Km$^2$) during 1986 to 2016. In the same period, the contribution of Open/sparse shrubland to the total land cover decreased from 33% to 11%, and Grassland decreased from 18% to 6%. In general bush (Closed Shrubland) encroachment affected about 2.2 million hectares.

**Table 9 Land cover of Kenya (1986-2016) for the Study area in Square Kilometer**

| S. N | Land cover | 1986 | | 2000 | | 2016 | |
|---|---|---|---|---|---|---|---|
| | | Area, in Km$^2$ | % | Area, in Km$^2$ | % | Area, in Km$^2$ | % |
| 1 | Agriculture and Settlement | 87 | | 118 | | 120 | |
| 2 | Bare Areas | 3864 | 5 | 3587 | 4 | 5266 | 7 |
| 3 | Closed Shrubland | 7048 | 9 | 14297 | 18 | 26719 | 33 |
| 4 | Closed Woodland | 825 | 1 | 705 | 1 | 691 | 1 |
| 5 | Grassland | 16594 | 21 | 13070 | 16 | 9700 | 12 |
| 6 | Open/Sparse Woodland | 11485 | 14 | 9311 | 12 | 6444 | 8 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 7 | Open/Sparse Shrubland | 40461 | 50 | 39278 | 49 | 31463 | 39 |
| 8 | Water Body | 22 | | 20 | | 16 | |
| | Total | 80386 | | 80386 | | 80386 | |

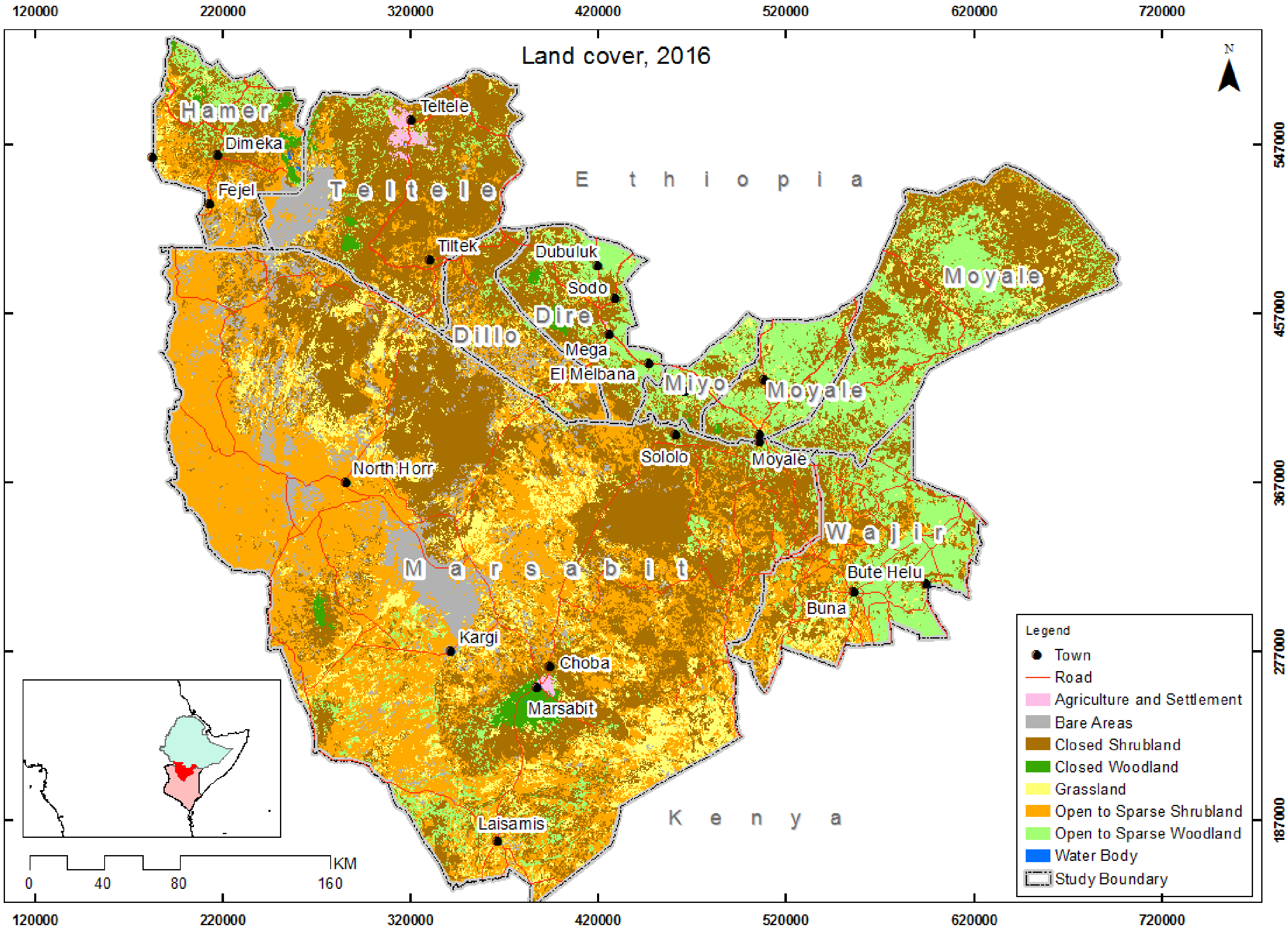


**Figure 9: Land cover map of the study area in 2016**

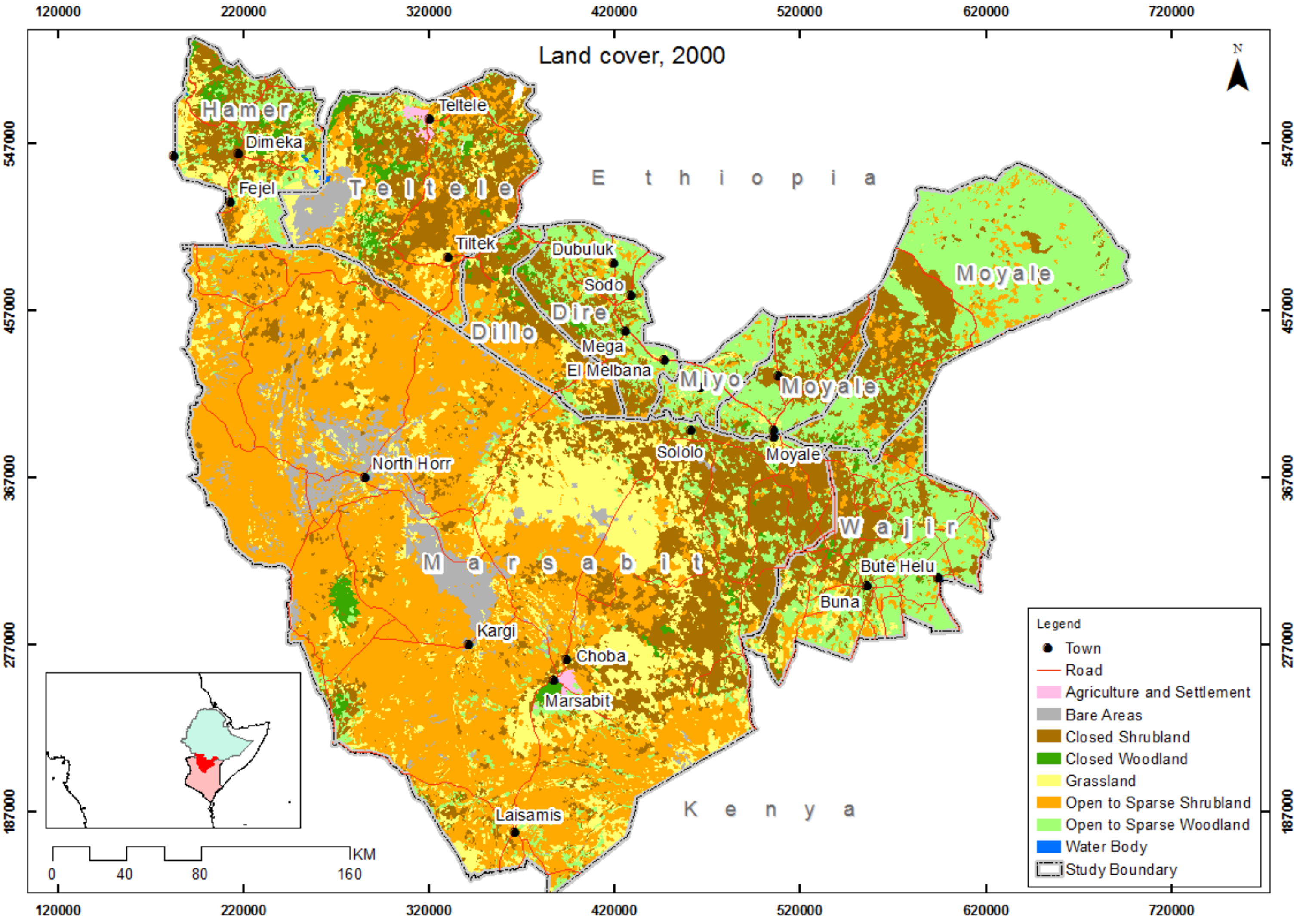


**Figure 10: Land cover map the study area in 2000**

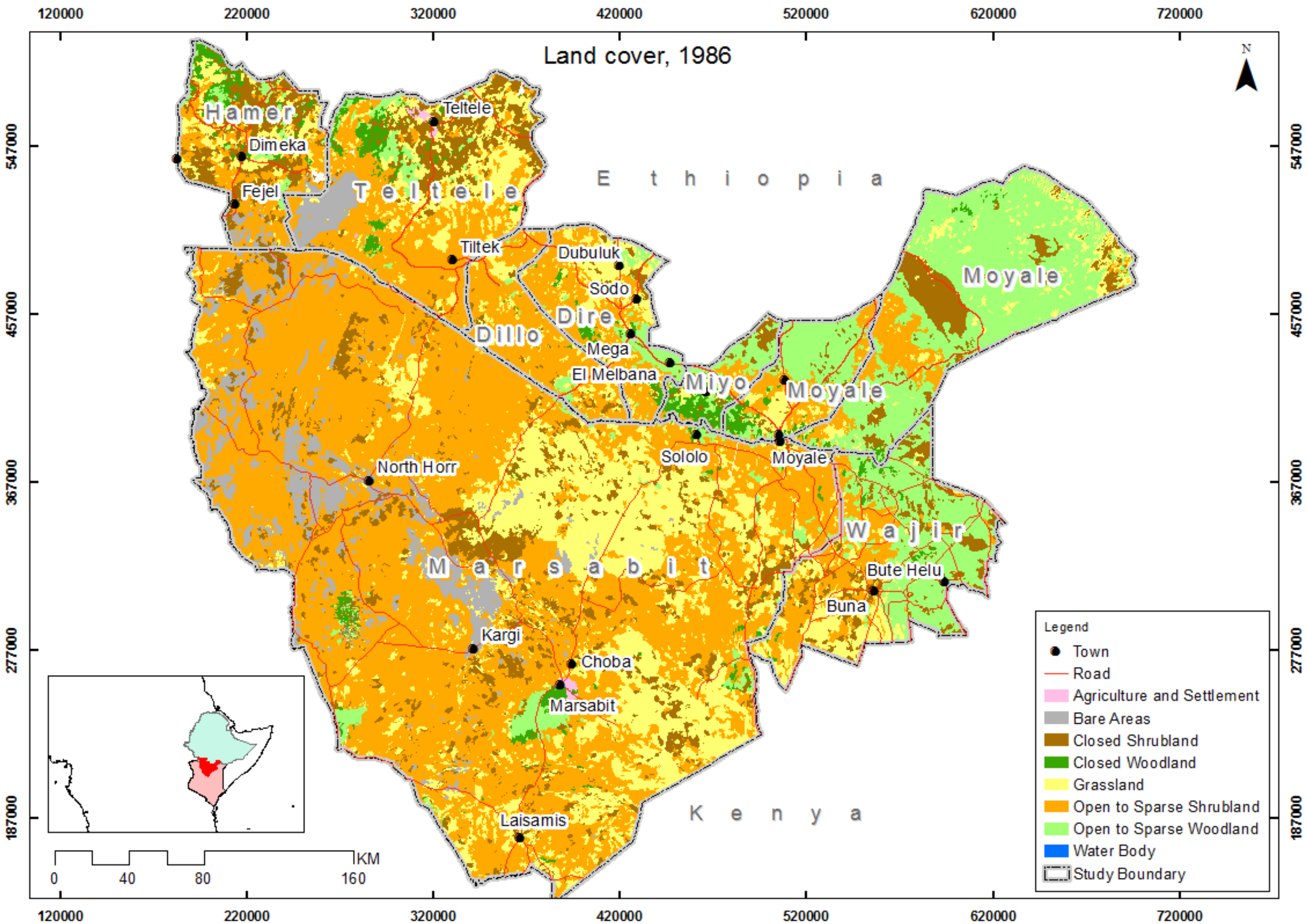


**Figure 11: Land cover map the study area in 1986**

## *5.4. Land cover change matrix*

### 5.4.1 Change Matrix (1986-2000)

The cross-tabulation matrices (Table 10) shows change in the different land cover classes or in other words the shift in the land cover classes between 1986 and 2000. The diagonal values highlighted in yellow indicate unchanged area during these period. Out of the 177km$^2$ that was under Agriculture and Settlement (AS) in 1986, 127 km$^2$ was remain Agriculture and settlement (AS) in 2000 but 62km2 was converted to Closed Shrubland (CS), Closed woodland (CW), Grassland (GRSS), and open to sparse woodland (OSW). The conversion of the rest of land cover feature can be interpreted in similar fashion. Most of the grasslands were converted to Closed Shrubland, Open/Sparse shrubland and Open/Spares woodland which is indicator of bush and invasive tree expansion. The conversion of woodland to agriculture and settlement is also an indicator of woodland degradation.

**Table 10: Land cover change matrix (1986-2000)**

| | Land cover 1986 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | LULC | AS | BA | CS | CW | GRSS | OSS | OSW | |
| Land cover 2000 | AS | 127 | 0.00 | 62 | 10 | 21 | 48 | 7 | |
| | BA | | 2285 | 134 | 3 | 393 | 2157 | 3 | |
| | CS | 10 | 145 | 4822 | 848 | 6106 | 14152 | 11162 | |
| | CW | 3 | 0 | 283 | 641 | 265 | 610 | 410 | |
| | GRSS | 14 | 341 | 1620 | 248 | 7345 | 6254 | 593 | |
| | OSS | 14 | 1885 | 4235 | 196 | 6171 | 37596 | 1578 | |
| | OSW | 21 | 52 | 2446 | 877 | 4007 | 4776 | 11151 | |
| | Total | 177 | 4708 | 13602 | 2823 | 24371 | 54895 | 23326 | |

**AS = Agriculture & Settlement; BA = Bare land; CS = Closed Shrubland; CW = Closed Woodland; Grass = Grassland; Open/Sparse Shrubland; OSW = Open to Sparse Woodland**

### 5.4.2 Change Matrix (2000-2016)

The diagonal value highlighted in yellow indicate that no change between 2000 and 2016. The conversion of Closed Shrubland to closed woodland might help to understand the activities related to bush clearance which contributes to the regeneration of noninvasive/indigenous woodlands. In this period about 6561 km$^2$ Grassland was converted to closed Shrubland which explains the extent of bush encroachment and invasive tree species in the study area.

**Table 11: Land cover change matrix (2000-2016)**

| | Land cover 2000 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | LULC | AS | CS | CW | GRSS | OSS | OSW | BA |
| Land cover 2016 | AS | 140 | 114 | 3 | 21 | 38 | 34 | 3 |
| | CS | 41 | 17333 | 427 | 6561 | 14593 | 8383 | 310 |
| | CW | 34 | 207 | 1351 | 196 | 107 | 310 | 0.00 |
| | GRSS | 31 | 1637 | 59 | 5273 | 5892 | 861 | 465 |
| | OSS | 7 | 5696 | 193 | 5479 | 21271 | 764 | 1840 |
| | OSW | 24 | 4090 | 255 | 799 | 2357 | 10141 | 17 |
| | BA | 0.00 | 283 | 0.00 | 679 | 3205 | 93 | 2326 |
| | Total | 277 | 29318 | 2198 | 19008 | 47463 | 20686 | 4961 |

**AS = Agriculture & Settlement; BA = Bare land; CS = Closed Shrubland; CW = Closed Woodland; Grass = Grassland; Open/Sparse Shrubland; OSW = Open to Sparse Woodland**

### 5.4.3 Change Matrix (1986-2016)

The characteristics of change of land cover feature in 20 years (1986-2016) is presented in Table 12. From the change matrix, Closed shrubland was converted to OSS. Grassland was largely converted to Closed shrubland, an indication of rangeland degradation in the study area.

**Table 8: land cover change matrix (1986-2016)**

| | Land cover 1986 | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | LULC | AS | CS | CW | GRSS | OSS | OSW | BA |
| Land cover 2016 | AS | 80 | 134 | 14 | 65 | 38 | 3 | |
| | CS | 21 | 6354 | 1406 | 10596 | 20986 | 6182 | 496 |
| | CW | 34 | 100 | 479 | 41 | 269 | 389 | 10 |
| | GRSS | 14 | 1461 | 159 | 3597 | 4993 | 1034 | 65 |
| | OSS | 7 | 3391 | 124 | 6585 | 22876 | 524 | 1732 |
| | OSW | 21 | 1881 | 627 | 2874 | 3453 | 15184 | 10 |
| | BA | 0 | 281 | 14 | 613 | 1280 | 10 | 2395 |
| | Total | 177 | 13602 | 2823 | 24371 | 54895 | 23326 | 4708 |

**AS = Agriculture & Settlement; BA = Bare land; CS = Closed Shrubland; CW = Closed Woodland; Grass = Grassland; Open/Sparse Shrubland; OSW = Open to Sparse Woodland**

### *5.5. Analysis of cross-border rangeland degradation*

Two types of Rangeland degradation were analyzed: 1) the degradation associated to expansion of invasive woody species and 2) the degradation that resulted from land use change.

### 5.5.1. Rangeland Degradation: Invasive Woody Species

Rangelands have been encroached by woody invasive species, which are mostly unpalatable and hinders mobility of animals due to their thorny nature. Compared to previous years, these species replaced many rangelands and pastures. This is a type of degradation associated with those non-palatable herbs, shrubs, and woody vegetation.

A similar study in Borena zone of Ethiopia estimated the extent coverage of *A. drepanolobium* and *A. mellifera* to 18% and 11% of the Borena range land (Abebe, 2009). A study by Terefe et al. (2011) shows that *A. drepanolobium* as the most dominant (22%) and abundant (65%) invasive woody species with an importance value index (IVI) of 1.3 in Borena rangelands followed by *Acacia mellifera*. Similar remote sensing and ground based study about *Prosopis Juliflora* in Hargeisa, western Somali, was found that it cover about 9% of the area considerd in the study (Michele, 2016).

From the current filed data, four dominant invasive woody species were identified namely, *A.drepanolobium*, *A.mellifera*, *A. reficiens* and *P. Juliflora*. It was mapped using satellite images and the four invasive species cover 15% of the area in Northen Kenya and 32% of the area in southern Ethiopia, within the study area. For example *A. Drepanolobium* covers less than 1% of the study area in the northern Kenya while its covers 15% in the southern Ethiopia. This is because the species is highly spread in the high altitude areas than low altitude areas like northern Kenya. Because altitude variation may sometimes cause variation in rainfall distribution which favors the species, especially in highlands Borena. The least distributed species is found to be *A.drepanolobium* 0.5% in northern Kenya and *Prosopis Juliflora* in southern Ethiopia (1.6%). Acacia melifera is widely spread in northern Kenya and southern Ethiopia with area cover of 7% and 12% respectively. *A. reficiens* has more area coverage in southern Ethiopia (8%) than in northern Kenya (4%) (Table 13).

**Table 9: Invasive Species Area coverage, Kenya & Ethiopia**

| S. N | Species Name | Area in Kenya | | Area in Ethiopia | | Total Area | |
|---|---|---|---|---|---|---|---|
| | | Area, $Km^2$ | % | Area, $Km^2$ | % | $Km^2$ | % |
| 1 | *Acacia drepanolobium* | 406 | 0.5 | 4853 | 11% | 5259 | 4 |
| 2 | *Acacia mellifera* | 5718 | 7 | 5187 | 12% | 10905 | 9 |
| 3 | *Acacia reficiens* | 2791 | 3 | 3332 | 8% | 6123 | 5 |
| 4 | *Prosopis juliflora* | 2884 | 4 | 705 | 2% | 3589 | 3 |
| | Total area of four species | 11799 | 15% | 14077 | 32% | 25876 | 21 |
| | Total study Area | 80386 | | 43584 | | 123970 | |

From the map indicated in Fig 12, *A. Mellifera* is distributed largely in Wajir and in part of Moyale woreda of Ethio-Somali. While *A. reficiens*, is widely spread in Dilo and Sololo rangelands of Ethiopia and Kenya, respectively. *Prosopis Juliflora* is seen close to settlement area such as Bute, Wajir, Karagi, Mykoni and North Hor and near water body and seasonal streams. *Prosopis Juliflora* is also spread in some areas of Dasench and Ngangatom woredas of Ethiopia. While *A. Mellifera* and *A. drepanolobium* are common in the rangelands of Borena zone and northern part of Marsabit county. *A. drepanolobium* mainly affects the northern part of Borena rangelands and Ethio-Somali woreda.

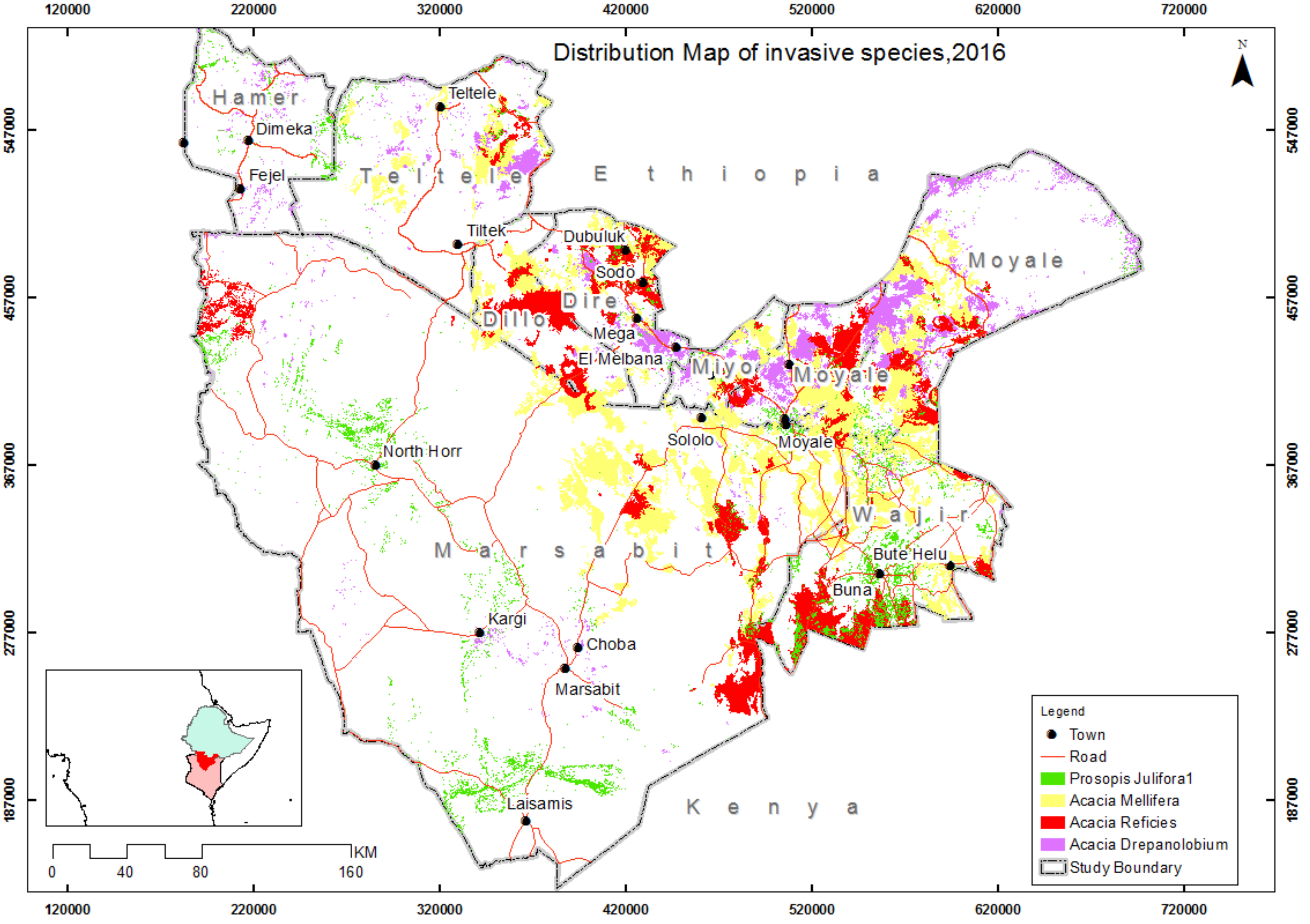


**Figure 12: Invasive Species spatial Distribution in 2016**

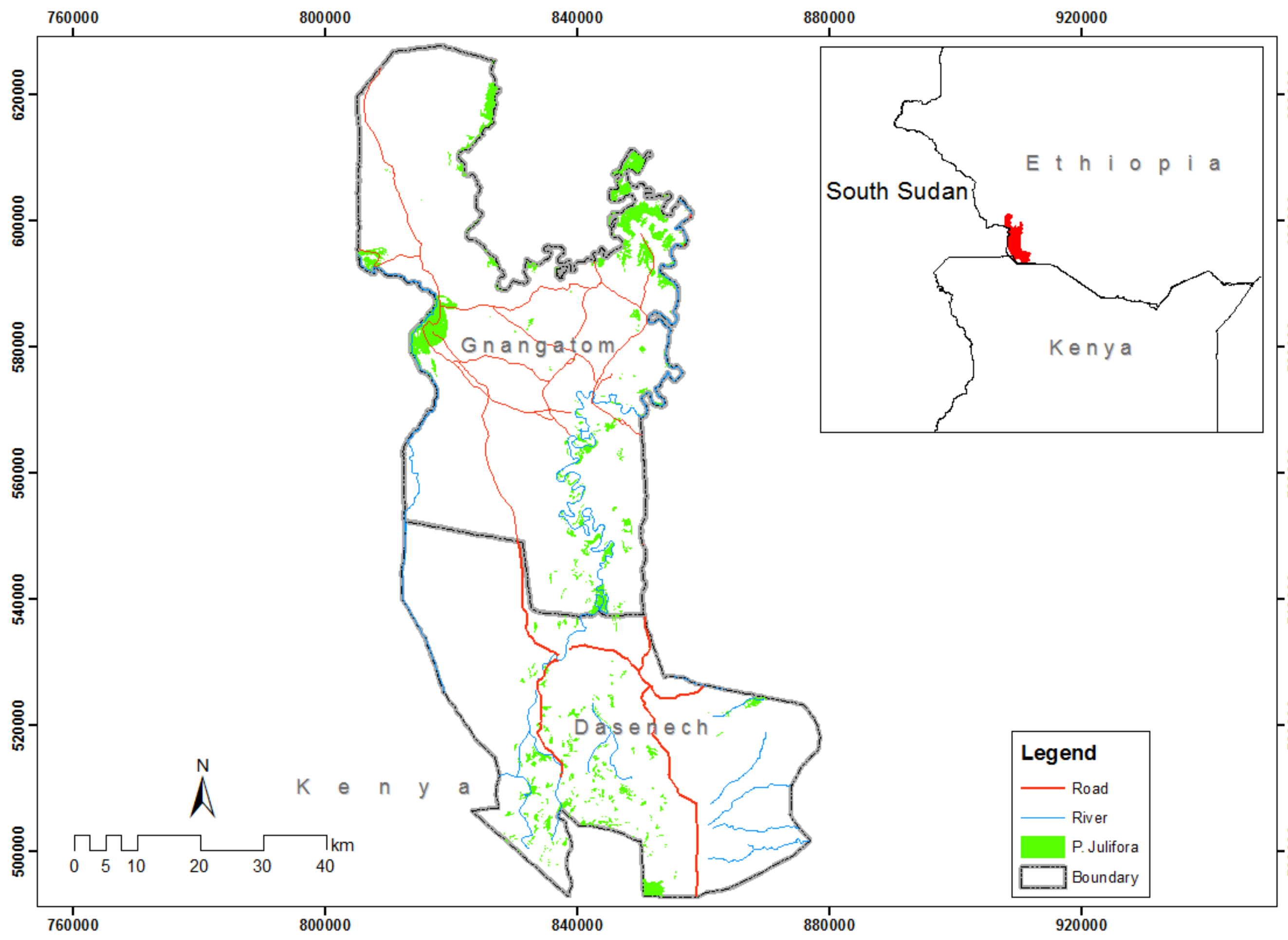


**Figure 13: P. Juliflora distribution in Dasenech and Nyangatom Woredas**

Table 14 Area coverage of P. Julifora in Dasench and Ngangatom, Ethiopia (2016)

| Species | Area, in hectare | |
|---|---|---|
| | Dasench | Ngangatom |
| P. Juliflora | 6000 | 15800 |

### 5.5.2. Cross border Rangeland Degradation

The second type of degradation was analyzed by considering land use change in the cross-border rangelands regardless of the species type. Five categories of degradation were identified namely Very high degradation, High degradation, Moderate degradation, Slight degradation, and unchanged. Based on the analysis 34% of the study area in Ethiopia falls in a Very high rangeland degradation category. While Very high rangeland degradation covers 18% of the study area in Kenya. High degradation covers 20 % and 16% in Ethiopia and Kenya rangelands respectively. Unchanged areas are areas either not degraded or desert areas with out vegetation.

**Table 10: Rangeland degradation area and percent in Ethiopia and Kenya**

| S. N | Degradation Status | Area in Ethiopia | | Area in Kenya | | Total | |
|---|---|---|---|---|---|---|---|
| | | Squ Km | % | Squ Km | % | Squ Km | % |
| 1 | Unchanged | 3572 | 8% | 7870 | 10% | | 9 |
| 2 | Slight degradation | 2878 | 7% | 17315 | 21% | | 16 |
| 3 | Moderate degradation | 13502 | 31% | 27140 | 34% | | 33 |
| 4 | High degradation | 8777 | 20% | 13431 | 17% | | 18 |
| 5 | Very High degradation | 14717 | 34% | 14460 | 18% | | 24 |
| | Total Project Area | 43670 | | 80504 | | | |

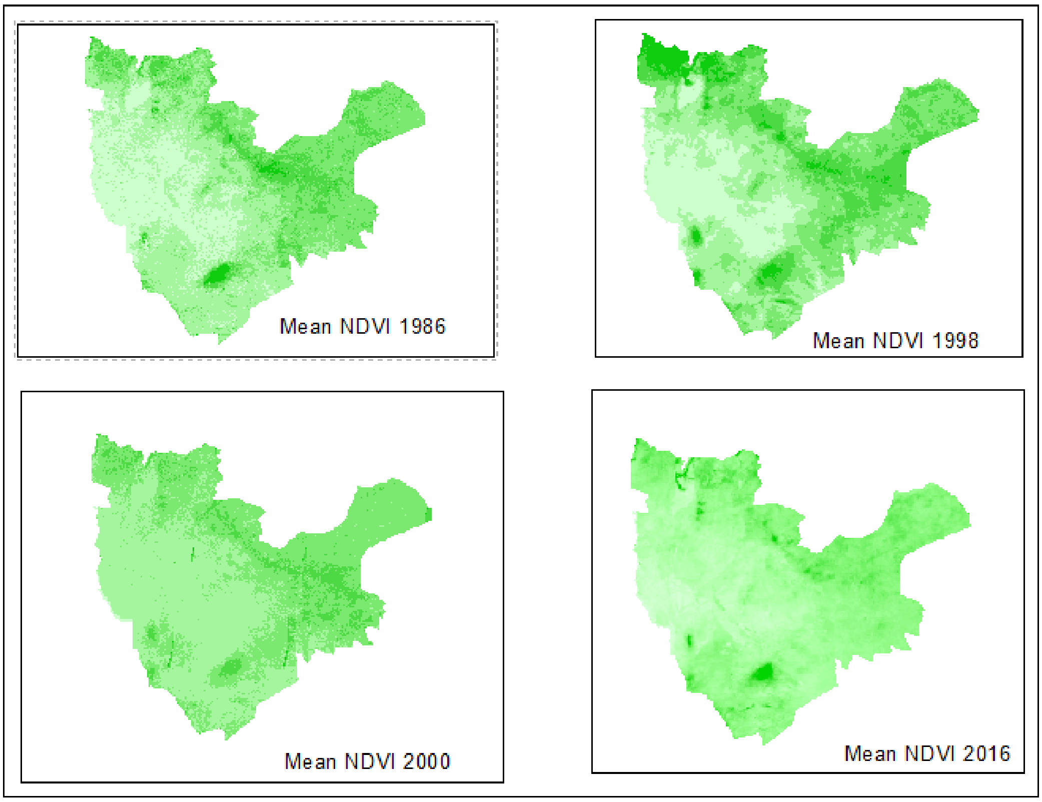


**Figure 14: Time series NDVI map**

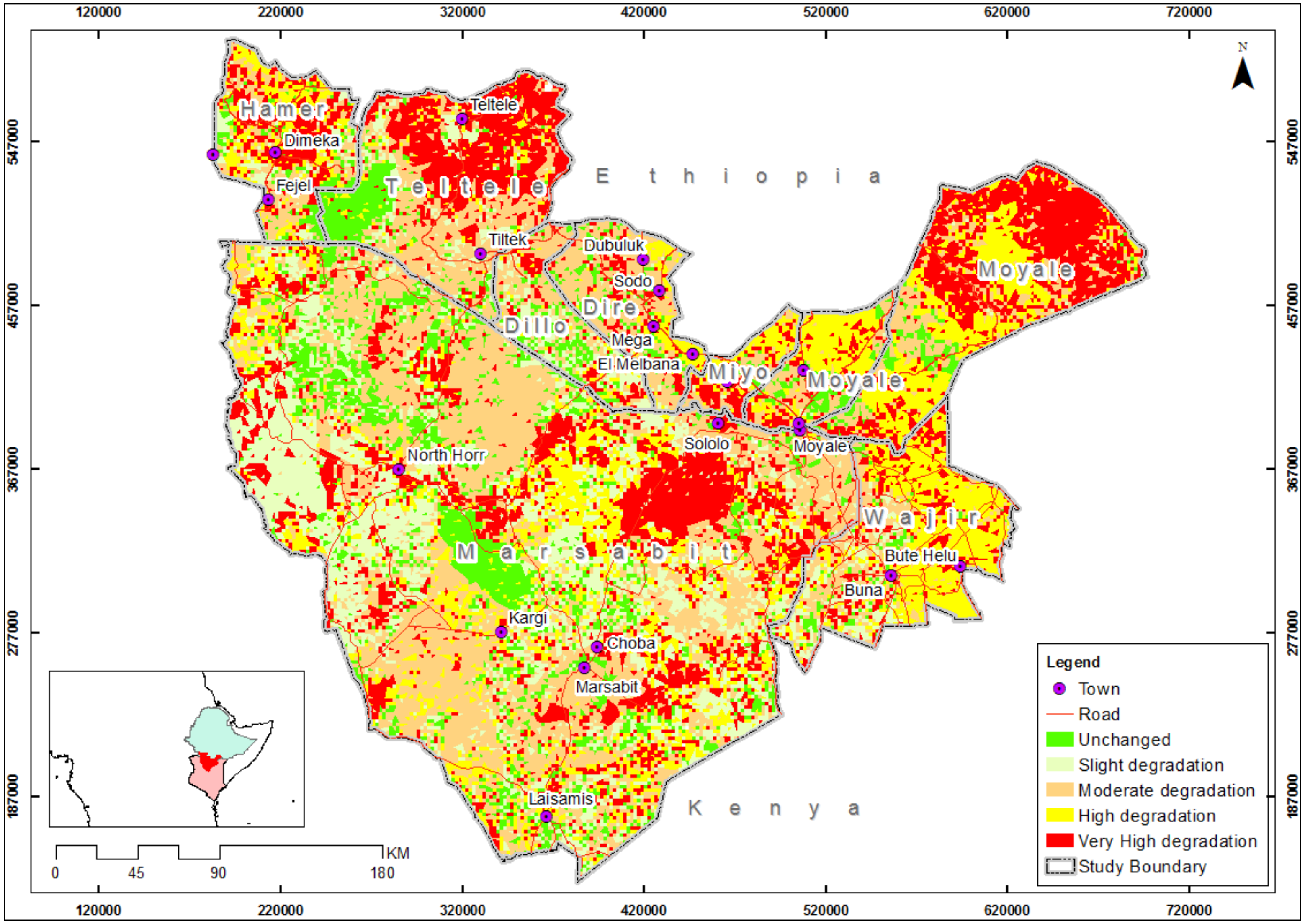


**Figure 15: Rangeland degradation Map (2016)**

## 6. Conclusion

The Mapping and analysis of cross border rangelands in southern Ethiopia and Norther Kenya was carried out on 11 administrative areas using Landsat satellite images acquired in 1986, 2000, and 2016. Field data collection was carried out through semi-structured interview, field observation and using handheld GPS. Object based image classification was used in eCognition software. The Maps with fourteen land cover classes were initially prepared based on FAO land cover classification system and later the classes were merged to 8 classes for analysis purpose. Land cover change detection was done based on the post classification method from (1986 to 2016). The overall classification accuracy is 88% with kappa coefficient of 0.82%.

Closed shrubland found to be the dominant land cover type in the project area followed by Open/Sparse Shrubland and Open/Sparse woodland. Agricultural and settlement areas seen to be increased since 1986. In contrary water bodies and closed woodland (forest) have been shrinking during same period.

In the study area, Closed Shrubland has increased by 260%, since 1986. Open/Sparse Shrubland and Grassland have decreased by 34% and 50% respectively. This indicates the expansion of closed Shrubland which constituts invasive and thorny species. Slight decrease in closed woody vegetation is attributed to expansion of Agriculture and settlement.

Four major invasive species were identified; these include *A. mellifera*, *A.drepanolobium*, *A.reficiens* and *P. juliflora*. *A. melifera* is found to be widely distributed in Ethiopia and Kenya which cover 12% and 7% of the study area respectively. *P. Julifora* found to be least distributed in southern Ethiopia with 2%.

Five categories of rangeland degradation were mapped and the analysis was made for the two study countries. In Ethiopia, 34% of the area fall under very high degradation category, while 18% fall under the same category in Kenya. Land cover unchanged area during the study period, covers 10% and 8% in Ethiopia and Kenya respectively.

The Borena rangelands, north part of Marsabit and western Wajir found to be highly degraded. The southeast Marsabit and Hammer found to be moderately degraded. Prosopis Juliflora is widely seen in Bute, Buna town in Wajir and North Hor, Karagi, and Laisamis in Marsabit. Also *P. Julifora* is seen in Ngangatom and Dasench woredas with area coverage of 158km$^2$ and 60.8km$^2$ respectively.

*A. Drepanolobium* is widely distributed in Borena range lands and Moyale in Oromia and in Ethiopia Somali. *A. melifera* is distributed in Teltele, Dilo, Miyo in Ethiopia and Sololo rangelands in Kenya.

## 7. References

Benz, U.C., Hofmann, P., Willhauck, G., Lingenfelder, I., Heynen, M., 2004. Multiresolution, object oriented fuzzy analysis of remote sensing data for GIS-ready information. ISPRS Journal of Photogrammetry and Remote Sensing 58 (3:4), 239:258.

B. Terefea, M. Limenihb, A. Gureb, A. Angassac,d IMPACT OF Acacia drepanolobium (AN INVASIVE WOODY SPECIES) ON GUM-RESIN RESOURCES AND LOCAL LIVELIHOOD IN BORANA, SOUTHERN ETHIOPIA. Tropical and Subtropical Agroecosystems, 14 (2011): 1063-1074

Hassan E. Adam, and Elmar C., Integration of Remote Sensing, GIS and Terrestrial Forest Inventory in Estimation of Acacia Senegal Tree Parameters, Technische Universität Dresden, Institute of Photogrammetry and Remote Sensing, Germany

Huete, A.R., (1988) 'A soil-adjusted vegetation index (SAVI)' Remote Sensing of Environment, vol. 25, issue 3, pp. 259-309. DOI: 10.1016/0034-4257(88)90106-X

J. H. ROSS An analysis of the African Acacia species: their distribution, possible origins and relationships. Bothalia 13, 3 & 4: 389-413 (1981)

K M Kafi, H Z M Shafri, A B M Sharif (2014) An analysis of LULC change detection using remotely sensed data; A Case study of Bauchi City, Department of Civil Engineering, Faculty of Engineering, Universiti Putra Malaysia, 43400.Serdang, Selangor Malaysia

K.Ragavan, J.Colins Johnny quantification of invasive colonies of Prosopis Julifora using remote sensing and GIS techniques. International Journal of Engineering and Technical Research (IJETR)ISSN: 2321-0869, Volume-3, Issue-5, May 2015

Oroda A S, Oduori S M, Vargas R, 2007: Applications of Remote Sensing Techniques for the Assessment of Pastoral Resources in Puntland, Somalia by FAO-SWALIM. Project Report No. L-11. Nairobi, Kenya

Romie J., Vincentius P., Bisman N, Lilik Budi P, Sam W Random forest classification for mangrove land cover mapping using Landsat 5 TM and ALOS PALSAR imageries.Procedia Environmental Sciences 24 (2015) 215 – 221

Tewodros T., Evangelista PH, Jarnevich CS, Laituri M (2014) Mapping Current and Potential Distribution of Non-Native Prosopis juliflora in the Afar Region of Ethiopia. PLoS ONE 9(11): e112854. doi: 10.1371/journal.pone.0112854,

Weng, 2001 Land use change analysis in the Zhujiang Delta of China using satellite remote sensing,GIS and stochastic modelling, Department of Geography, Geology, and Anthropology, Indiana State University, Terre Haute, IN 47809, USA

# 8. Annex

## *Annex 1: Sentinel2 scene used for invasive species mapping*

S2A_OPER_MSI_L1C_TL_MTI__20160115T095047_A002949_T37NBC

S2A_OPER_MSI_L1C_TL_MTI__20160115T095047_A002949_T37NEC

S2A_OPER_MSI_L1C_TL_MTI__20160122T094038_A003049_T37NEC

S2A_OPER_MSI_L1C_TL_MTI__20160122T094038_A003049_T37NFF

S2A_OPER_MSI_L1C_TL_MTI__20160309T013104_A003521_T37NBD

S2A_OPER_MSI_L1C_TL_MTI__20160309T013104_A003521_T37NCB

S2A_OPER_MSI_L1C_TL_MTI__20160309T013104_A003521_T37NCC

S2A_OPER_MSI_L1C_TL_MTI__20160309T013104_A003521_T37NCD

S2A_OPER_MSI_L1C_TL_MTI__20160309T013104_A003521_T37NCE

S2A_OPER_MSI_L1C_TL_MTI__20160309T013104_A003521_T37NDB

S2A_OPER_MSI_L1C_TL_MTI__20160309T013104_A003521_T37NDC

S2A_OPER_MSI_L1C_TL_MTI__20160309T013104_A003521_T37NDD

S2A_OPER_MSI_L1C_TL_MTI__20160309T140506_A003378_T37NDE

S2A_OPER_MSI_L1C_TL_MTI__20160309T140506_A003378_T37NEE

S2A_OPER_MSI_L1C_TL_SGS__20160125T113126_A003092_T37NBE

S2A_OPER_MSI_L1C_TL_SGS__20160201T113300_A003192_T37NED

S2A_OPER_MSI_L1C_TL_SGS__20160201T113300_A003192_T37NEE

S2A_OPER_MSI_L1C_TL_SGS__20160201T113300_A003192_T37NEF

S2A_OPER_MSI_L1C_TL_SGS__20160201T113300_A003192_T37NFC

S2A_OPER_MSI_L1C_TL_SGS__20160201T113300_A003192_T37NFE

S2A_OPER_MSI_L1C_TL_SGS__20160217T115519_A003421_T36NZL

S2A_OPER_MSI_L1C_TL_SGS__20160217T115519_A003421_T37NBD

S2A_OPER_MSI_L1C_TL_SGS__20160217T115519_A003421_T36NYL

S2A_OPER_MSI_L1C_TL_SGS__20160217T115519_A003421_T36NZJ

S2A_OPER_MSI_L1C_TL_SGS__20160217T115519_A003421_T36NZK

S2A_OPER_MSI_L1C_TL_SGS__20160217T115519_A003421_T36NZL

S2A_OPER_MSI_L1C_TL_SGS__20160217T115519_A003421_T37NBD

S2A_OPER_MSI_L1C_TL_SGS__20160217T115519_A003421_T37NBE

S2A_OPER_MSI_L1C_TL_SGS__20160217T115519_A003421_T37NBF

## Annex 2: List of Landsat Scene used for land cover mapping

P166R057

P167R057

P167R058

P167R059

P168R056

P168057

P168R058

P168R059

P169R057

P169R058

## Annex 3: Initial land cover classification

| LC | LCC Code | LCC Level | LCC Label | Map Code |
|---|---|---|---|---|
| 1Forest | 20001 | A1A10 | Closed Woody Vegetation | 1 |
| 2Woodland | 20009 | A1A11 | Open Woody Vegetation | 2 |
| 6Sparse Vegetation | 20049 | A1A14 | Sparse Woody Vegetation | 3 |
| 3Thicket | 20017 | A4A10 | Closed Shrubland (Thicket) | 4 |
| 4Shrubland | 20021 | A4A11 | Open Shrubs (Shrubland) | 5 |
| Agriculture | 11371-12630 | A3XXXXC2D1-C3C7C18 | Rain fed Herbaceous Crop(s) (One Additional Crop) (Herbaceous Terrestrial Crop with Overlapping Period). | 7 |
| 1Built Up Areas | 5003-9 | A4-A13 | Urban Area(s) | 9 |
| 2Unconsolidated Bare Areas | 6006-6 | A6-A12 | Stony Loose and Shifting Sands | 10 |
| 1Artificial Waterbodies | 7002 | A1B1 | Artificial Perennial Waterbodies | 11 |
| 1Artificial Waterbodies | 7003 | A1B2 | Artificial Non-Perennial Waterbodies | 12 |
| 5Grasslands | 20033 | A6A10 | Closed Grassland | 13 |
| 5Grasslands | 20045 | A6A11 | Open Grassland | 14 |
| 1Natural Waterbodies | 8002 | A1B1 | Perennial Natural Waterbodies | 16 |
| 1Natural Waterbodies | 8003 | A1B2 | Non-Perennial Natural Waterbodies | 17 |
| 1Artificial Waterbodies | 7003-28 | A1B2-A5B9 | Artificial Non-Perennial Waterbodies (Water presence 3-1 months) (Standing) | 18 |

### *Annex 4: Sample points per land cover class*

| S. N | Sample Name | Sample Number |
|---|---|---|
| | *A. Mellifera* | 13 |
| | *A. Reficiens* | 10 |
| | *Waterbody* | 7 |
| | *closed woodland* | 13 |
| | *closed Shrub* | 38 |
| | *Bare Area* | 14 |
| | *Grassland* | 18 |
| | *open to sparse woodland* | 25 |
| | *P. Julifora* | 13 |
| | *Agriculture and settlement* | 36 |
| | *open to sparse Shrub* | 26 |
| | *A. drepanolobium* | 11 |
| | Total | 224 |

### *Annex 5: Accuracy Assessment Matrix (2016)*

| S. N | LULC | AS | CS | CW | GR SS | OS S | OS W | WB | BA | Tot al | User Accuracy |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | AS | 15 | 0 | 0 | 1 | 1 | 0 | 0 | 1 | 18 | 83.33 |
| 2 | CS | 0 | 25 | 2 | 0 | 2 | 1 | 0 | 0 | 30 | 83.33 |
| 3 | CW | 0 | 0 | 45 | 0 | 0 | 2 | 0 | 0 | 47 | 95.74 |
| 4 | GRSS | 3 | 2 | 0 | 30 | 1 | 0 | 1 | 1 | 38 | 78.95 |
| 5 | OSS | 0 | 0 | 0 | 2 | 15 | 1 | 0 | 1 | 19 | 78.95 |
| 6 | OSW | 0 | 2 | 3 | 0 | 0 | 46 | 0 | 0 | 51 | 90.20 |
| 7 | WB | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 10 | 100.00 |
| 8 | BA | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 38 | 42 | 90.48 |
| | Total | 19 | 29 | 50 | 34 | 20 | 51 | 11 | 41 | 255 | |
| | Producer Accuracy | 78. 95 | 86. 21 | 90. 00 | 88.2 4 | 75. 00 | 90. 20 | 90. 91 | 0.9 3 | | |

Overall Accuracy = 87.84; Kappa = 0.82

### *Annex 6: Questionnaire*

Country: - Kenya County: -______________________

Name of the place: -_______________

RPLRP coordinator name____________________________

Mob: -_____________________________________________ email: -___________________

Name of places/county under RPLRP Project

1. 
2. 
5. 
6. 

3. 7.
4.

1. Are you familiar with any woody invasive species in the area under your supervision in RPLRP project or other projects?
   A. Yes B. No

   If yes please give the local name of the invasive species and its characteristics

   ______________________________________________________________________
   ______________________________________________________________________
   ______________________________________________________________________
   __________________________________

2. Since when the species is introduced and mode of introduction, is it introduced intentionally or unintentionally with some important event? Please, explain

   ______________________________________________________________________
   ______________________________________________________________________
   ______________________________________________________________________
   __________________________________

3. Is there a conflict
   A. Yes B. No

If yes, please indicate the reason among the following choices

A. Due to water and grass
B. Due to a tribe difference
C. Due to political cases
D. Other______________________________________________________
______________________________________________________________
____________________

4. How do you explain the occurrence of the conflict?
A. Cross border with neighboring countries
B. Cross border within the country among counties
5. How frequent is the conflict?
   A. Very high
   B. High
   C. Moderate
   D. Low
6. What are the specific seasons of conflict in the area?

   ______________________________________________________________________
   ______________________________________________________________________
   ________________________

7. Is there any water harvesting and rangeland conservation practice implemented by any entity
   A. Yes B. No

If yes please, specify the type of conservation practice including the water harvesting technologies

______________________________________________________________________
______________________________________________________________________
_________________________

8. What are the major challenges you experienced to introduce modern pastoralist development technology in your area?

________________________________________________________________________
________________________________________________________________________
________________________

9. Do you have seen any potential for alternative income generating activities in the area?
   A. Yes B. No

12. If yes please, indicate among the following options

   A. Bee keeping
   B. Soap production
   C. Timber Production

Other please, specify

________________________________________________________________________
________________________________________________________________________
________________________

Thank you!!!!

### *Annex 7: Land cover Sample collection format*

Name of the country/county________________

| S. N | GPS ID | Picture ID | X coordinate | Y-coordinate | Description of Land cover/use | Invasive species type | Local Name of the nearby Place/town |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
| | | | | | | | |

### *Annex 8: List of werda and county in the Study Areas*

| S. N | Name of the werda/County | Region/county | Country |
|---|---|---|---|
| 1 | Marsabit | Marsabit | Kenya |
| 2 | Wajir North | Wajir | Kenya |
| 3 | Hammer | SNNP | Ethiopia |
| 4 | Dasench | SNNP | Ethiopia |
| 5 | Ngangatom | SNNP | |
| 6 | Teltele | Oromia | Ethiopia |
| 7 | Dire | Oromia | Ethiopia |
| 8 | Meyo | Oromia | Ethiopia |
| 9 | Dilo | Oromia | Ethiopia |
| 10 | Moyale | Oromia | Ethiopia |
| 11 | Moyale | Somali | Ethiopia |

### *Annex 9: Local and English Name of the Invasive Species*

| S. N | | Local name | English Name | District/county affected |
|---|---|---|---|---|
| | *Acacia drepanolobium* | Fulinsa | Whistle thorn | Dire, Moyale |
| 1 | *Acacia mellifera* | Suphansa | Black thorn | Hammer, Teltele, Meyo, Dilo |
| 3 | *Acacia reficiens* | Sigirso | False umbrella thorn | Marsabit, Moyale, Dilo |
| 4 | *Prosopis Juliflora* | | Mesquites | Marsabit, Wajir, Ngangatom, Dasench |

### *Annex 10: DN value of Major invasive Species*