



***Decision Tree based Cropland and Crop Type Mapping using
MODIS EVI data for Ecosystem Services Assessment, A Case of
Lake Tana Sub Basin***

**Thesis submitted for partial fulfilment of the requirements for the award of
the Degree of Master of Science in
Remote Sensing and Geographical Information Systems (GIS)**

By

Yohannes Aragie

Under the guidance of

Dr. K.V. Suryabhagavan

Assistant Professor, School of Earth Sciences
Addis Ababa University, Addis Ababa

And

Dr. Gete Zeleke

Director, Water and Land Resource Centre, Addis Ababa

School of Earth Sciences
College of Natural Sciences
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Acknowledgments

Foremost, I would like to express my sincere gratitude to my advisor Dr. K.V. Suryabhagavan, Assistant Professor, School of Earth Sciences, Addis Ababa University, for his guidance and valuable suggestions during the research work.

I would like to express my special appreciation and thanks to my co-advisor Dr. Gete Zeleke, Director, Water and Land Resource Centre, Addis Ababa, for his constant encouragement, helpful discussions and valuable suggestions and providing all the financial assistants and creating a convenient environment for the successful completion of the thesis.

I am equally indebted to Mr. Tibebu Kassawmar, Water and Land Resource Centre, Addis Ababa, for the valuable help rendered and time spared. Without his encouragement and guidance this thesis would not have materialized.

I would like to express my special appreciation to Dr. Kaspar Hurni, Centre for Development and Environment, University of Bern, Switzerland, for the valuable suggestions and time spared during the research work

I also wish to thank Dr. Seifu Kebede, Head, School of Earth Sciences, Addis Ababa University, for his generosity in extending facilities and funds to me to submit this thesis.

I am greatly indebted to all my family members for their helpful nature throughout my assignment and my wife Mrs. Meaza Moges, Abubaker Aragaw, Meron Moges, and my children Rakeb and Eldana for the care and support during the work. But for their cooperation, I would not have completed this thesis in time.

My whole hearted thanks are also due to all my friends, whose names could not be mentioned separately because of limitations; for their constant encouragement and cooperation. I am thankful to the almighty for the divine blessings showered up on me to complete this work.

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Abbreviations

AER	Agro Ecological Region
ASTER	Advanced Space borne Thermal Emission and Reflection
CGR	Crop Growing Region
DT	Decision Tree
DEM	Digital Elevation Model
EHRS	Ethiopian Highland Reclamations Study
EVI	Enhanced Vegetation Index
GCP	Ground Control Points
GIS	Geographic Information System
IDL	Interactive Data Language
LTSB	Lake Tana Sub Basin
LULC	Land-Use/Land-Cover
MEA	Millennium Ecosystem Assessment
MoA	Ministry of Agriculture
MoARD	Ministry of Agriculture and Rural Development
MODIS	Moderate-Resolution Imaging Spectro-radiometer
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
PVI	Perpendicular Vegetation Index
RS	Remote Sensing

RVI	Ratio Vegetation Index
SPOT	Satellite Positioning and Tracking
TCC	Traditional Cropping Calendar
WAO	Woreda Agricultural Office
WOCAT	World Overview of Conservation, Approaches and Technologies

Abstract

Mapping cropland and characterizing their surface vegetation cover for major crops growing in the region over time and space is an essential input to many applications including, natural resources assessment, food security monitoring and economics of land use practices. For such applications, multi temporal remote sensing data and GIS techniques play important role both as source of data and techniques. This paper took the advantage of the multi-temporal Moderate Resolution Imaging Spectro-radiometer (MODIS) Enhanced Vegetation Index (EVI) data to map cropland and types of crop growing in the study area and characterize their surface cover vegetation variability. The output of the study used to assess implications with respect to ecosystem services mainly grain production, soil erosion and sediment load to Lake Tana. To map the types of crops, MODIS EVI data integrated with Traditional Cropping Calendar (TCC) and a decision tree based classification algorithm were used. The overall approach of the study is summarized in four major steps; 1) Separating cropland from the non-cropland, 2) identifying and mapping the different types of crops, 3) characterizing the vegetation dynamics of different crops over time and space and 4) Assessing major ecosystem service and disservice of growing different crops in the study areas. The proposed methodology revealed promising results in separating cropland from the non-cropland ones with 75% of an overall accuracy whereas crop type mapping was done with 60% of accuracy. Relatively the poor classification accuracy for crop type map is due to the high landscape variability of the study area, smaller spatial resolution of the MODIS data which is less than individual plot. Nonetheless, crop type mapping accuracy can further be improved if more criteria are established. Lake Tana Sub Basin (LTSB) cropland is dominated by Teff cultivation that exposed the region for more soil erosion risk. The final outcomes of the present study could support researchers to develop a crop phenology from multi-temporal data like MODIS. Moreover, maps of different crops growing in the basin could help to evaluate the economic benefit of different land use practices. Using the developed crop type maps, the spatio-temporal surface cover condition and biomass over the cropland could be inter-related with several ecosystem disservices mainly soil loss and sediment load in a particular watershed.

Keywords; *Cropland, Ecosystem Services, MODIS data, Multi-Temporal, Traditional Cropping Calendar,*

CHAPTER ONE

1.1 Introduction

Land degradation is defined as a long term loss of natural ecosystem function and productivity (Ivits *et al.*, 2009). There are a number of interrelated land degradation forms that contribute to the declining of ecosystem services (WOCAT, 2007). Literally it exists in four major forms namely: soil erosion, declining of vegetation, biodiversity loss, and water resources reduction (Ivits *et al.*, 2009). Among these forms of degradation, soil status and vegetation cover are the two basic and interdependent ecosystem services on which the status and management of one affects the other (MEA, 2003). Moreover, many of these components are easily mappable using satellite imageries while management practices, types of crops growing in a particular time, over a cropland is very challenging for remote sensing specialists.

Among the land degradation components, soil erosion has remained very critical in the highlands of Ethiopia. According to Hurni (1983), four major contributing factors can be identified for soil erosion as a major form of land degradation: rainfall erosivity, soil erodibility, land slope and land use. He revealed that by far the most important factors is land management, followed far behind by slope, erodibility and erosivity. Therefore, according to Hurni's argument land degradation process is typically exacerbated through land use change in general that significantly determine erodibility of land through changing cover and slope of the land. In Ethiopia 80% of the soil erosion comes from cropland. Generally, while land degradation is widespread and serious in the highlands of Ethiopia, only general and rather qualitative estimates exist of its severity, extent and distribution (EHRS, 1986). Hence, mapping cropland surface cover type and type of crops growing in time and space is an essential input for many applications including, natural resources assessment, food security monitoring and economic land use modelling. So far, studying and quantifying crop type and cover in a cultivated landscape process has remained a challenging issue. Existing information are based on sample based and qualitative data and helps little for better resource management. Hence supplementing it by adding quantitative information is an important aspect of research. Timely and reliable information about cropland and crop type distribution is important to assess the environmental impacts associated with the different cropping practices. For such application, remote sensing and Geographic Information System (GIS) plays an important role both as source of data and techniques.

Remotely sensed data have long been used to characterize cropland at regional and global scales (Xiao *et al.*, 2003; Xiao *et al.*, 2005; Lobell and Asner, 2004). Therefore, the present study tried to separate croplands from the non-cropland and later map the different types of crop growing over the cropland. Eventually, the spatio-temporal surface vegetation dynamics of the cropland is characterized so that its implication on major ecosystem services and disservices can be assessed.

1.2 Statement of the Problem

Lack of cloud free data during the growing seasons of crops and inappropriateness of existing classification algorithms for complex landscapes like the highlands of Ethiopia, cropland and crop type mapping has remained a research gap. However Moderate Resolution Imaging Spectro-radiometer (MODIS) based crop type mapping has never been done in the highlands of Ethiopia. For such complex problems analysing multi-temporal data like MODIS and mapping issues, which require combining multi-criteria rules are labours and time consuming but can be resolved efficiently with programming. Hence, the present study employees MODIS based characterizing of crop lands and crop types through programing approaches.

1.3 Objective of the study

1.3.1 General Objective

The present study aims to develop crop phenology character from remote sensing data and eventually map the crop types, surface vegetation condition and assess the inter-linkage with ecosystem services and disservices

1.3.2 Specific objectives

- To separate cropland from non-cropland using Moderate Resolution Imaging Spectro-radiometer (MODIS) satellite images
- To map major crop types growing in the study area
- To characterize the surface cover variability of cropland over season of the year
- To link surface cover condition of croplands with erosion and sediment process over a season

- To establish a geo-informatics database system that allows evaluating and predicting yield and biomass

1.4 Hypotheses of the study

At the initial stage of the research it was hypothesised that using multi-temporal data it is possible to separate cropland from the non-cropland in a systematic way. Moreover, once the cropland are efficiently separated developing potential crop type maps for major crops growing in the study area is even simpler with multi-temporal data as different crops do have different growing calendar.

1.5 Limitation of the study

Landscape complexity, limited ground information and poor spatial resolution of the image used which exceeds the plot size of the farmers were some of the major challenges to effectively implement the proposed methodology.

1.6 Scope of the study

The entire analysis was done in Lake Tana Sub Basin (LTSB) and two major reasons attributed to select the study area: its diverse bio-physical and socio-economic condition makes it an ideal region. It is one of the potential development corridors at country level where several development projects are being implemented. The scope of the study is to test the potential/applicability of MODIS hyper-temporal EVI data to separate cropland and non-cropland as well as mapping crop types within heterogeneous landscape. To make use of MODIS data and test its potential for the intended objectives, the study also includes the development of appropriate classification approaches to accomplish the intended objectives. Such kind of research sometimes require collection of long term primary data. However with in the time-frame of MSc thesis, collecting long-term primary data is not feasible. As a result available secondary data, short field visit and consultation of individual farmers were employed.

CHAPTER TWO

2. Literature review

2.1 Application of remote sensing for Land-use/Land-cover mapping

Land-use/Land-cover (LULC) maps are vital for monitoring, understanding and predicting the effects of complex human-nature interactions that span local, regional, and global scales. Up-to-date information on land surfaces and the state of the environment are critical components of environmental planning and management. Such kind of digital LULC mapping and analyses is as old as equal as the age of remote sensing technology (Lillesand and Kiefer, 1987). Method wise assessment of the overall environmental system in general and cropland in particular, using the conventional techniques have high costs associated with field-based monitoring. Many researchers advice that for successful LULC mapping the best approach shall consider the data accessibility, low cost, synergy of different data types. For that reason, contextualized modification and innovative methodological framework formulations are principles to be followed that can ensure effective and accurate LULC mapping against the factors that reduce the mapping accuracy. However, alternatives to integrate the traditional knowledge and medium to high resolution remotely sensed data, standard geographic data and derivative products are currently becoming best options for such complex environmental system assessment.

Several studies showed that, there is a strong tradition of using data from medium resolution sensor (10-70m) especially Landsat for mapping LULC and monitoring change at local to national level (Lillesand and Kiefer, 1987). Satellite data from Moderate Resolution Imaging Spectro-radiometer (MODIS), Landsat, Satellite Positioning and Tracking (SPOT) and Advanced Space borne Thermal Emission and Reflection (ASTER) offer reasonable resolution to map LULC at broader scale. In earlier times, this level of spatial resolution had been considered as sufficient enough for detecting important land use patterns at reasonable scale. However, the maps developed from these different data sources still have problems related to spatial scale, reference, polarized classification approaches and data errors. Moreover making comparison between one another is remained a challenge for remote sensing specialists. Nonetheless, it is still remained sole options to use them because of the high cost of higher spatial resolution datasets. Researchers often use the data they can afford, not the data they truly

need (Hansen *et al.*, 2008). Specifically for large heterogeneous areas, like the Ethiopian highlands, the data needs are very intensive and expensive.

According to Hansen *et al.* (2008), one of the limitations of coarse resolution multispectral imageries is that land feature classes have smaller dimension than the pixel size of the imageries. However, multi-temporal data have still potential to map land features having dynamic character over season of the year. The importance of using Enhanced Vegetation Index (EVI) multi temporal data as compared to one time multispectral data based mapping of LULC is that the influence of atmospheric effect, the topographic and shadowing effect, and data redundancy are significantly reduced. LULC mapping and change analysis using multi-temporal EVI data are well documented. Recorded results from previous studies have demonstrated that it is feasible to develop an automated land-cover monitoring system (Coppin and Bauer, 1995) from EVI and/or Normalized Difference Vegetation Index (NDVI). EVI and/or NDVI thresholds and measures of phenological amplitudes have been used in land-cover classifications (DeFries *et al.*, 1995; Loveland and Belward, 1997; Loveland *et al.*, 2000).

2.2 Remote Sensing data and techniques to map cropland

Segregating cropland from non-cropland has remained a challenging exercise for remote sensing specialist. In Ethiopia, the literature review revealed that there has no similar research been done. However, in other countries there exist a number of researches conducted employing multi-temporal satellite data to map croplands. Hence, it is possible to separate cropland from non-cropland. Recent studies have indicated that the Moderate Resolution Imaging Spectroradiometer (MODIS) data has high potential for mapping crops. The application of time-series data or phenology-based analysis has been the basis of many cropland mapping applications using MODIS data (Chang *et al.*, 2007; Wardlow *et al.*, 2006; Wardlow *et al.*, 2007; Xiao *et al.*, 2005).

Phenology is the study of the seasonal timing of the recurring events, such as sowing, emerging, flowering, leaf senescence of plants (Lieth, 1974; Ivits, *et al.*, 2009). Evaluation of the phenological process is an important observable phenomenon that helps to understand and interpret the nature of vegetation in a particular agro ecology. Phenological behaviour of vegetation can be observed, analysed and mapped using temporal profiles of vegetation indices (Ivits *et al.*, 2008). Derived metrics decompose the vegetation indices time series curve into a

set of variables e.g. in terms of start, end and length of growth season, annual biomass production and relative split into permanent and seasonal components of vegetation cover. These indices are found to be objective, repeatable and are well corrected with the biophysical conditions that are crucially defining real world vegetation phenology (Ivits *et al.*, 2009). Therefore, phenological metrics and their trends could show a high potential for functional classification of various status of crop types, their biomass, and yield over time and space.

Out of the different satellite raw data and products, MODIS 16 day Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) data are widely used for mapping purpose. Although NDVI/EVI data have been proved to be extremely useful, they can only be used properly when the user is aware of the limitations of the data. Nonetheless to the major objective of the present study which focuses mainly to extract cropland from the non-cropland ones, usefulness of NDVI/EVI is very clear. If the cropping calendar and types of crop growing for a particular Agro Ecological Region (AER) is known temporal vegetation index could help to separate the cropland from the non-cropland. In this regard, NDVI/EVI are not the only vegetation index available so far. There are also other techniques and indices which need to be assessed and used, with a range of complexities such as the Ratio Vegetation Index (RVI) and the Perpendicular Vegetation Index (PVI) that takes into account the soil emissivity (one of the major limitations of NDVI). However, EVI product of MODIS image is becoming very popular and useful. Hence EVI data of MODIS is intentionally selected to test its applicability and usefulness for the intended purpose of the present study. Lobell and Asner (2004) found high inter-class variability and low intra-class separability for MODIS 16-day 250 m NDVI for cropland mapping resulting from sub-pixel heterogeneity.

2.3 Approaches to map crop types and crop cover over time and space

Studies have shown that remotely sensed data have significant potential to analyse and evaluate crop type mapping and studying the spatio-temporal dynamics of a cropland surface cover. The integration of remote sensing data, Geographic Information System (GIS) techniques, and landscape ecology methods have emerged as promising area to understand cropland dynamics (Lambin *et al.*, 2003; Liverman *et al.*, 1998; Hurni *et al.*, 2005).

Using Moderate Resolution Imaging Spectro-radiometer (MODIS) time-series data, Xiao *et al.* (2005) characterized rice field distributions in southern China. Chang *et al.* (2007) examined the potential of using MODIS 500 m data for the mapping of corn and soybean of the United

States. The unique Normalized Difference Vegetation Index (NDVI) profiles associated with rice transplanting, growing and fallow periods were found to be particularly useful in their mapping exercise. Wardlow *et al.* (2007) analyzed time-series data for individual crop types and concluded that MODIS 250 m NDVI data had sufficient spatial and temporal resolution for major crop type identification in Kansas, USA.

2.4 Crop Type mapping and Classification techniques

In mapping Land-use/Land-cover (LULC), not only the accuracy of the data but also the appropriateness of the method determine the quality of the information. Therefore, the selection of a classification algorithm and the analytical approaches are also important considerations to achieve an optimal LULC results (Duda, 2001). Other than remote sensed data, sometimes, it appears that incorporating agricultural census data or other crop statistics can further improve the mapping results. Currently, decision tree is one of the most commonly used classification technique which suit best for multi-temporal and multi criteria based classification approach (Chang *et al.*, 2007; Wardlow *et al.*, 2008). For the present study a decision tree algorithm was selected for mapping cropland and latter to map the types of crops along with their surface cover condition.

2.5 Cropland ecosystem services and assessment techniques

According to Nachtegraele and Petri (2008); Ivits *et al.* (2009), vegetation cover is an observable phenomenon that allows to indirectly assess soil erosion and sediment yield at different scale. Soil erosion, being a major aspect of land degradation, is also heavily conditioned by surface vegetation cover. Especially, in areas where quite majority (80%) of the soil loss are generated from cropland knowing the temporal variability of the surface cover condition of cropland is paramount importance (Tibebu Kassawmar, 2013). Therefore, land degradation studies shall base on accurate land use change in general and surface vegetation cover dynamics information of the cropland. In this regard understanding and estimating soil erosion, phenological derived indices from satellite images better describe the land degradation status than the climatic data (Ivits *et al.*, 2009). Land degradation can be approximated by the data derived from time series of vegetation indices and phenological indices derived from time series of remote sensing images offer important advantages when compared to simple vegetation indices for assessment of vegetation state and possibility to assess degradation. Ivits

et al. (2009) argued that land degradation might be successfully indicated by various phenological indices because these values have the capability to capture land use information that the one-time information fail to manifest. Hence, transforming the Normalized Difference Vegetation Index (NDVI) data to a phenological based information of different crops will improve the information needed to assess ecosystem services.

In summary, the reviewed literature shows that MODIS data based methodologies of cropland and crop type mapping do exist. However, many of them are specific to a particular region and specific to crops. In relation to the study area i.e Lake Tana Sub Basin (LTSB) in particular and Ethiopia in general it wasn't possible to find any research article related to the problem statement stated in the introduction part of present study. From the review, it was learnt that hyper-temporal data based crop type mapping demands area specific characterization of crop type phenology. This makes employing straight forward mapping approaches for heterogeneous landscape is impractical. Therefore, developing approaches by adapting other studies and systematizing the mapping process in a way that it fits the complex bio-physical and socio-economical setting has been found paramount importance

CHAPTER THREE

3.1 Description of the study area

Lake Tana Sub Basin (LTSB) is part of the greater Blue Nile Basin located at the North Western part of Amhara National Regional State of Ethiopia. The larger LTSB is administered by five major zones of the region namely; South Gondor, North Gondor, East Gojam, West Gojam and Bahirdar Liyu Zone. Geographically, it is bounded by latitude $12^{\circ}46'00''$ – $10^{\circ}56'00''$ N and longitude $36^{\circ}36'00''$ – $38^{\circ}32'00''$ E covering a total area of 15098 km² (Fig.1).

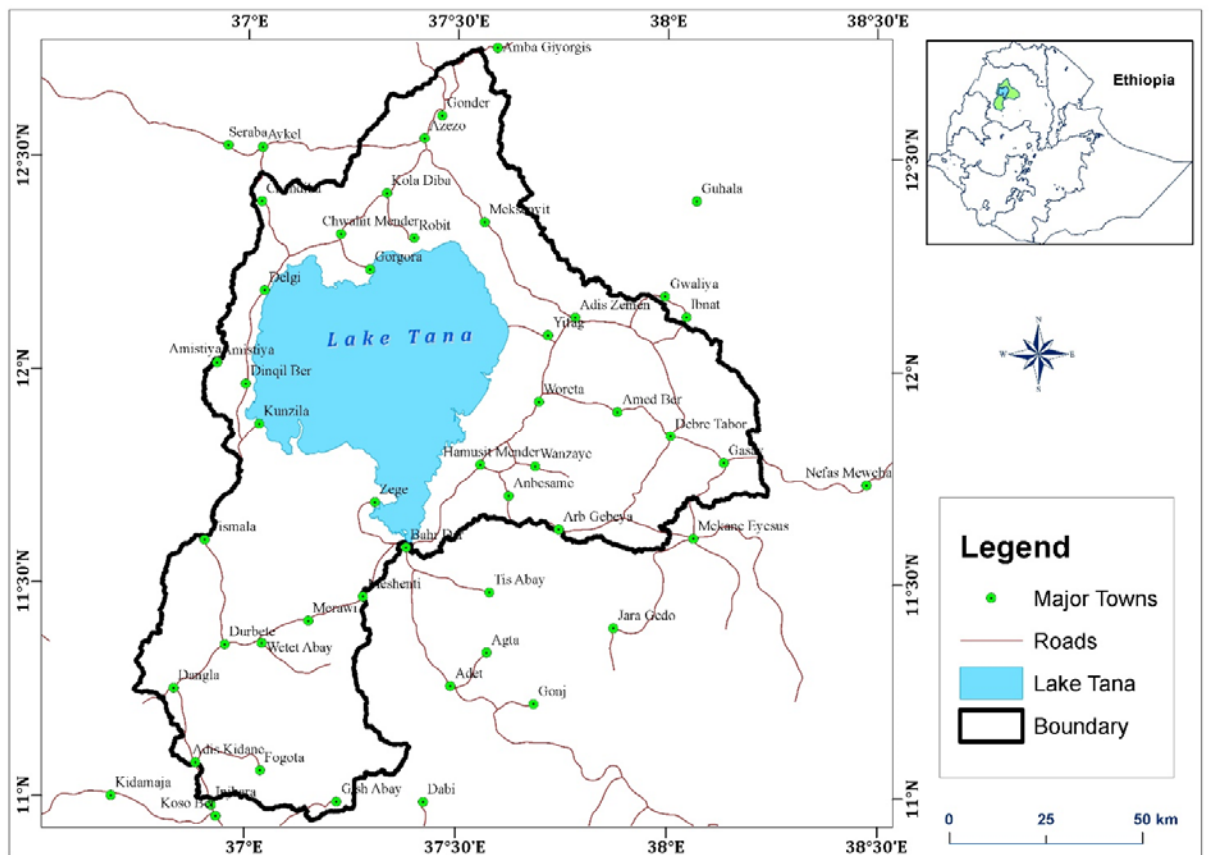


Figure 1: Location map of the study area

3.2 Biophysical settings

Lake Tana Sub Basin (LTSB) topographic setting is represented by rugged terrain near to its divide line and gets gentle to flat down to Lake Tana. The LTSB elevation difference ranges from 1783m to 4238m. The presence of substantial elevation difference in the basin created

distinct land forms, vegetation landscape, wetland landscapes, and various crop and livestock production opportunities. The entire LTSB forms a circular basin in which all the rivers flow down to the centre of the basin i.e. Lake Tana.

According to MoARD (1998), the floodplain part of LTSB is characterized by mono-modal rainfall pattern, i.e., with single growing season. The rainy season commonly starts at the last week of June and ends in Mid-September. However, with some variability, sometimes, rainfall starts in mid-May which can also vary from early May to end of May. The long-term mean daily temperature of LTSB ranges from 19.1°C - 25.51°C. The agro-ecology of the area, based on traditional agro-ecology classification is midland in the floodplain and highland in the middle and moist in the extreme end (i.e., at Guna and Sekela areas). The average annual rainfall in the floodplain is estimated to be 1067 mm in Dembia, 1123 mm in Libo Kemkem and 1296 mm in Fogera. According to Ministry of Agriculture sub-agro ecological zonation, the Tana plain is classified as Tepid to cool moist plains. (Fig. 2).

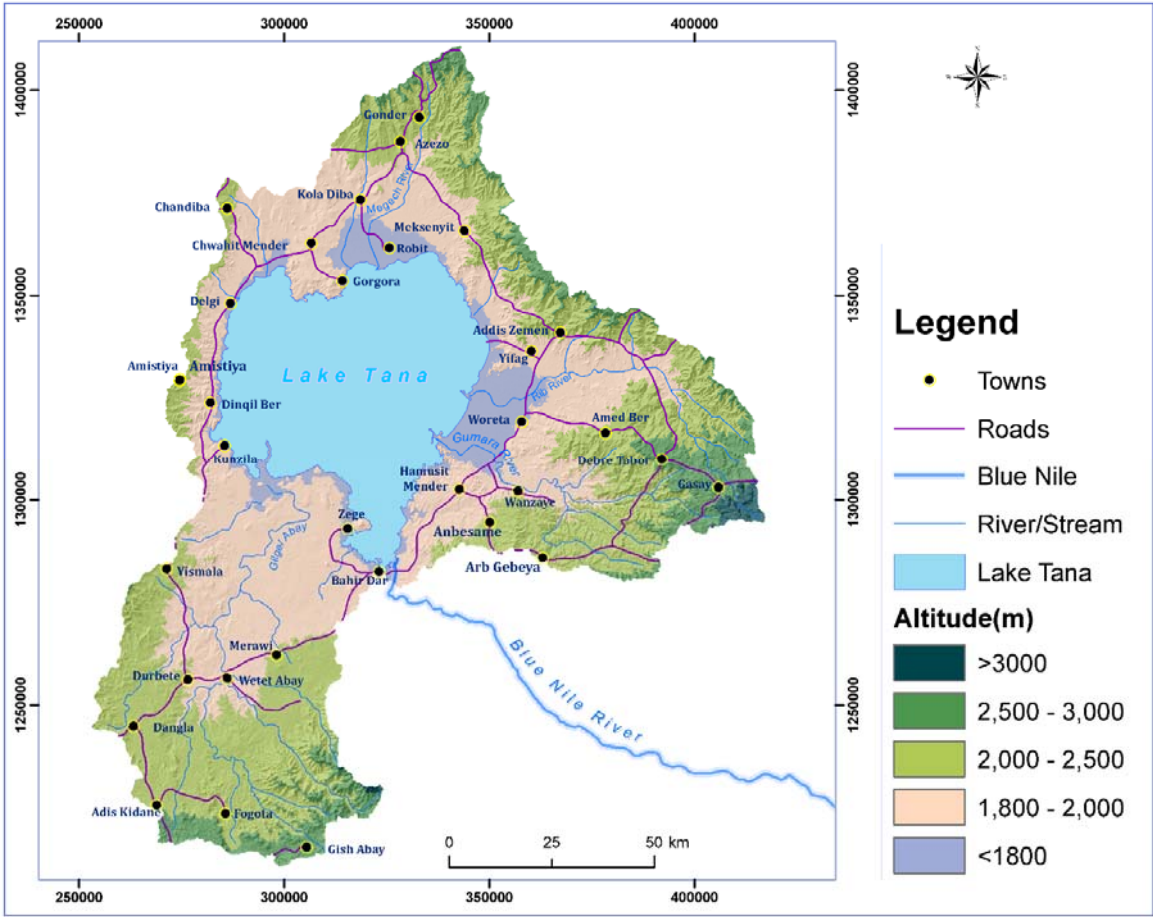


Figure 2: Topography map of the study area

3.3 Socio-economic conditions

Lake Tana Sub Basin (LTSB) has an immense resource for example, water resources, crop production, and fishery that can accommodate diverse livelihood options. In the basin agriculture is the main livelihood sector consists of two major sub-sectors namely; crop production and livestock production. The current livelihood is dominantly agro-pastoralism both in the upland and floodplain. According to information from local people 50 years ago the dominant occupation of the people living around Lake Tana was pastoralism. In the floodplain, livestock rearing was the largest economic activity, which has been practiced for centuries in an extensive production. The livestock management follows an extensive grazing on swamps, crop residue and crop aftermath.

3.4 Materials and Methods

3.4.1 Overall approach of the study and data used

The overall approach of the study can be summarized in four major steps; 1) Separating cropland from the non-cropland, 2) identifying and mapping the different types of crops, 3) characterizing surface vegetation condition of different crops over time and space and 4) Evaluating the potential of the findings to make an assessment for selected ecosystem services and disservices of growing different crops within the cropland (MEA, 2003). Major data sources were 1) Satellite images, 2) Secondary data obtained from Woreda Agricultural Office (WAO) and 3) Primary data collected in the field (Table 1).

Concerning the satellite data, Moderate Resolution Imaging Spectro-radiometer (MODIS) Enhanced Vegetation Index (EVI) for the year 2008 – 2013 and Landsat based Land-use/Land-cover (LULC) map (Tibebu Kassawmar, 2013) were used. The LULC data developed from Landsat served as reference as well as validation of MODIS based maps developed by employing the proposed methodology. Additionally, the WAO data for 2013 production years were used to fully employ the proposed methodological approach.

Table 1: Detailed description of the data used

SN	Data	Type	Time	Source	Nature of the data	Reason of use
I	Satellite data					
	Landsat	TM sensor Multispectral	2013	NASA	Processed and semi-processed	To separate cropland from non-cropland
	MODIS Multi-temporal data	EVI- Raw as well as Timsat fit	2013	NASA	Processed and semi-processed	To separate cropland from non-cropland For crop type identification and mapping
II	Secondary data	Crop Types, area coverage and Yield	2013	WAO	Different state and not credential b/c operated	For comparison purpose
		Farming System and Official Crop Calendar	Average	WAO	Conventional	To develop functional relationship between satellite data based crop phenology as well as yield estimation with the actual condition
II	Primary data	Productivity by each crop	2013	Farmers	Actual	
		Traditional Cropping Calendar	Average	Farmers and local area knowledge		

3.4.2 Croplands and non-cropland separation

To identify and re-group pixels that represent croplands, two major methodological approaches were employed namely subdividing the study area into Agro Ecological Region (AER) and clustering of analogous Moderate-Resolution Imaging Spectro-radiometer (MODIS) bands into smaller bands based on seasons of the year. Once the three major AERs have been subdivided into 14 regions, full range of MODIS data was grouped into five cluster of bands that represent the major crop growing season where spectral behaviour of the land surface greatly varies. On the bases of the divided cluster and region of the study area, pixel values that represent cropland for each AER in each cluster of bands was determined.

With these initial threshold values, decision rules have been set for each AER with each cluster of band. The classification process was done using ENVI Interactive Data Language (IDL) programming technology. The actual classification process applies a specific decision rule for each region separately. However, the classification process was programmed in a way that it considers the whole study area with all required rules and datasets and gives the result in a simple button click. Once the initial map has been produced, the process was iterated by changing the threshold for each AER where there is deviation in reference to Landsat map or ground reality. Finally best representing threshold values were obtained that properly represent cropland. Accuracy assessment was done so that the competence of MODIS Enhanced Vegetation Index (EVI) 16-day composite with 250 m time-series data to segregate cropland from the non-cropland can be ascertained.

3.4.3 Potential and dominant crop type mapping

After croplands have been properly mapped, on the developed cropland map, it was tried to identify and map major crop types by correlating their phenological property collected on the spot for each Crop Growing Region (CGR). To identify and map pixels that represent a particular crop type, three major methodological approaches were employed namely subdividing the study are into CGR and clustering of MODIS bands into similar and manageable bands, developing crops phenology on the bases of Traditional Cropping Calendar (TCC) and multi-temporal data of MODIS. To improve the classification accuracy, reference data about the type of crop, area coverage and yield for each crop type were collected at Kebele

level. On the bases of the types of crop growing in the entire study area, CGRs were developed for the whole study area. Once the CGR regions have been developed full range of MODIS 23 band data was also re-grouped into five cluster of bands that represents the crop phenology. On the bases of the divided CGR, cluster of MODIS data and TCC established for major crops in each CGR of the study area, range of pixel values that represent particular crop type was iteratively formulated. Initial threshold values have been established with the help of relating the TCC with the multi-temporal data of MODIS. With these threshold values, decision rules have been set for each CGR for each cluster of band and each type of crops. The classification process was done using ENVI IDL programming. The actual classification process was done region by region independently for each crop. Once the initial map has been produced, the process was iterated by changing the threshold for each AER. Where deviation to the reference kebele data is observed the iteration process continued till better result is obtained. Finally best representing crop type maps were developed.

3.4.4 Spatial variability of surface vegetation condition

After knowing which pixels represent what type of crop, it was found conceivable to characterize surface vegetation condition of the overall cropland. To do that, each crop type maps were used to mask the original MODIS data. Following that, the entire crop growing time has been divided into three major vegetation characterizing indicators, Bareness, Greenness and Greyness. Each stage of the crop phenology were translated into these vegetation character which is mappable. Eventually, surface vegetation condition of the cropland was characterized.

3.4.5 Ecosystem assessment

Proper assessment of ecosystem service and disservice demands accurate and spatially explicit geospatial information. In this regard, such kind of assessments are commonly facing challenges due to lack of spatially explicit data which always exposed the assessment either under estimation or over estimation. However, the present study took multi-temporal remote sensing data which could reasonably address the problem. In this regard spatial information like cropland area, area of individual crop types and yield were taken as important ecosystem assessment indicators. Moreover, local level information were obtained from Woreda

Agricultural Office (WAO) and compared with the remote sensing results. Simple comparison techniques were employed how these types of information are commonly over estimated or under estimated. The detailed methodological flow chart is presented in (Fig. 3).

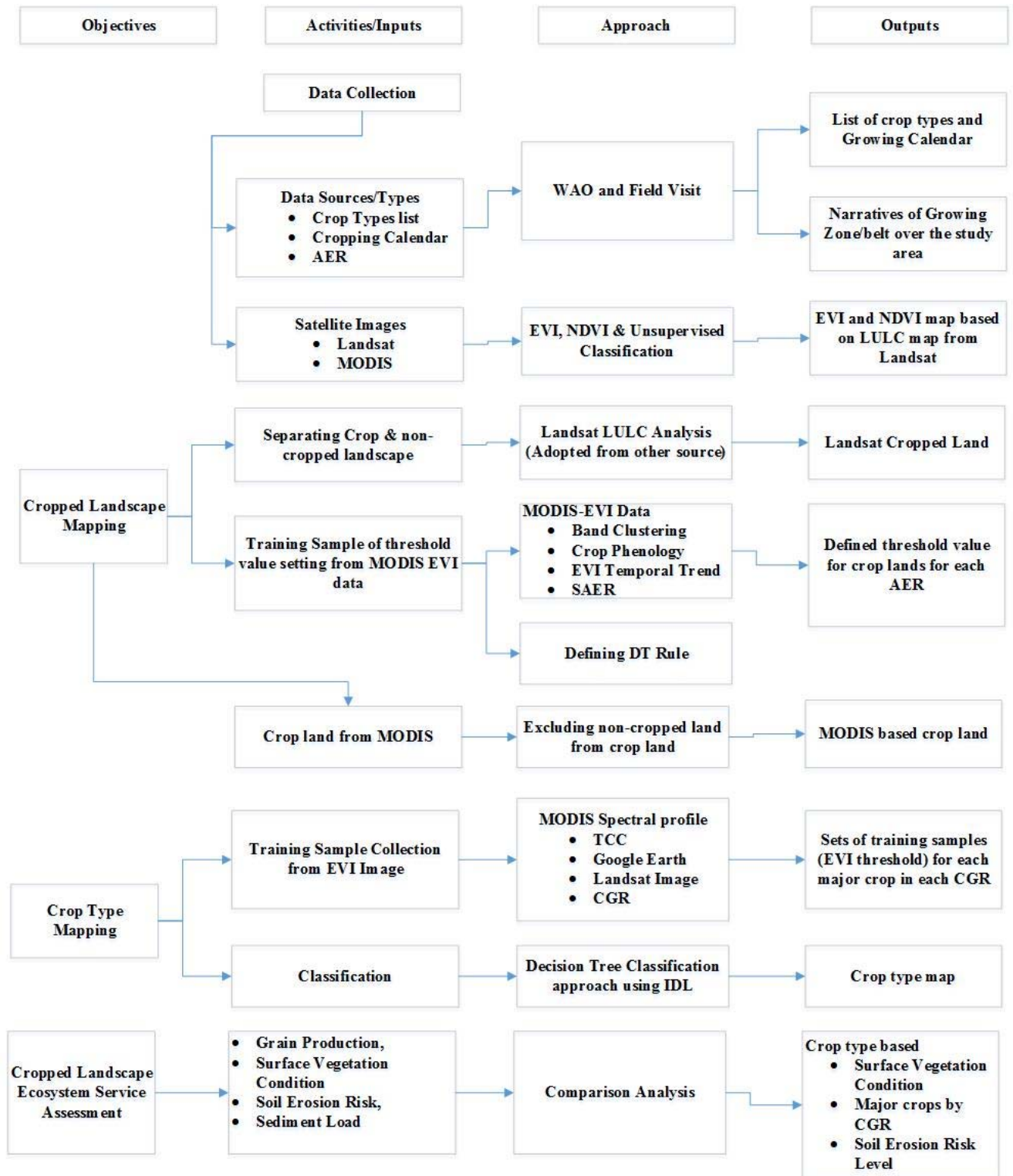


Figure 3: Methodology Framework

CHAPTER FOUR

Results and Discussions

4.1 Cropland and non-cropland mapping

4.1.1 Integrating multi-temporal data and multi-criteria rules

Several Land-use/Land-cover (LULC) mapping attempts implemented on heterogeneous landscape of Ethiopia, often in the highlands, have ignored the challenges of altitude variation. As a result, the accuracy of the maps remained less helpful for several applications. The present study was conceptualized after proper assessment on major shortfalls of the available LULC mapping techniques. On the basis of factors for the inaccuracy of the LULC maps and the inappropriateness of the mapping exercises simplistic and reproducible approach was developed.

Most importantly, a common mistake in mapping landscapes is considering extensive and heterogeneous areas as one unit of analysis, which significantly reduce the mapping accuracy of a particular satellite image. Cognizant to this problem, at early stage of the study, in order to effectively differentiate the cropland from the non-cropland, the study area has been subdivided into three major Agro Ecological Region (AER). In the process it has been realized that further sub-dividing the AER into more units had improved the classification accuracy. As a result, major AER of Lake Tana Sub Basin (LTSB) are further subdivided in to 14 sub-AER where soil, rainfall, farming system and vegetation condition are supposed to be similar (Fig. 4).

On the other hand, LULC mapping using multi-spectral one time satellite images have limitations to discriminate land features at a required level. But multi-temporal data have better capability to differentiate land features even in more complex and heterogeneous landscape settings. In fact due to the complexity and lengthy preprocessing steps that multi-temporal data require, often remote sensing specialists prefer to use one time satellite data. One time based satellite data mapping is an effective way on areas where land features have less dynamic spectral property over a particular period of the year. For instance, croplands are represented by all types of earth surface and have different spectral signature over different season of the year. As a result, separating croplands from other land features using one time images is often a difficult exercise. These types of land features can be separated if and only if the mapping process employs multi-temporal data with multi-criteria approach.

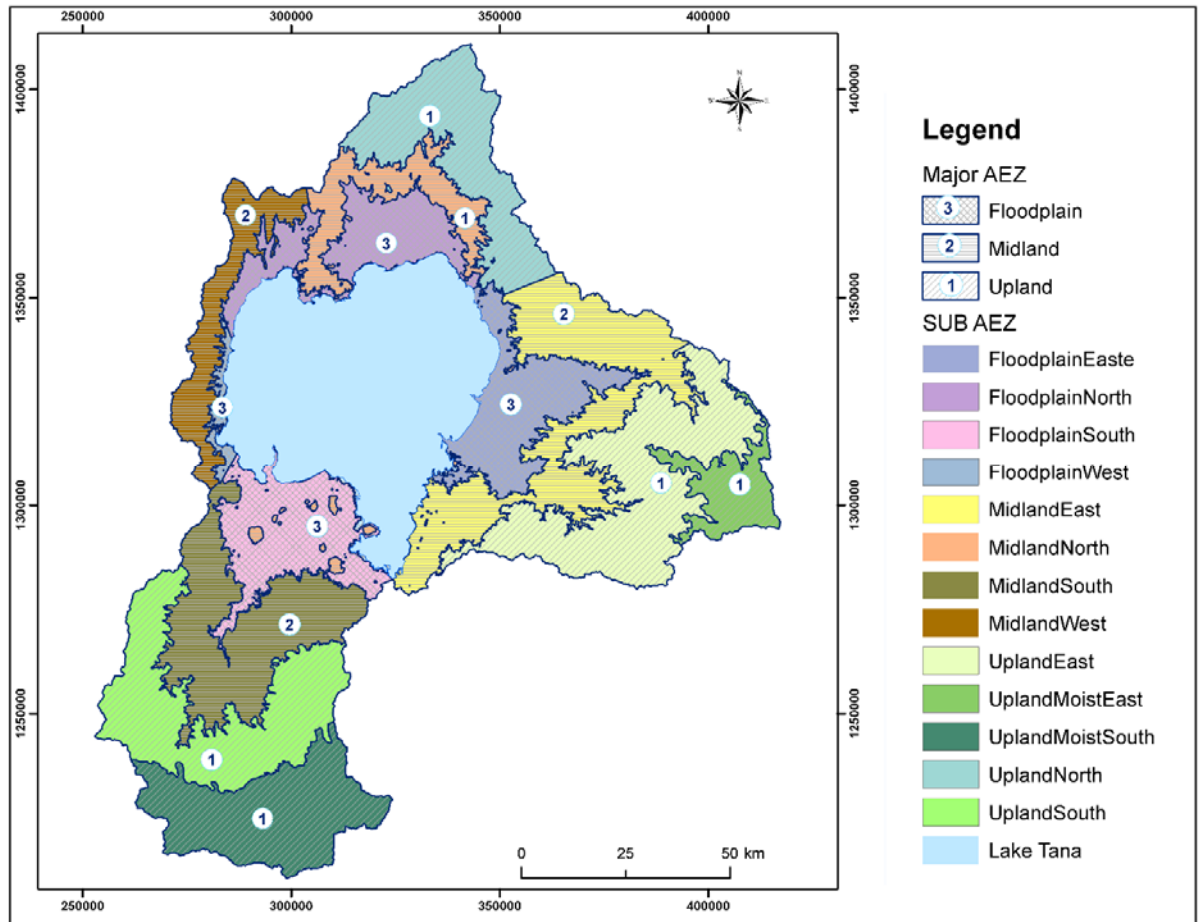


Figure 4: Major AER from MoA & and Sub AER developed by the study

Taking the Lake Tana as center of the study the major Agro Ecological Region (AER) was further subdivided into more smaller zones where farming system varies each major AER has been labelled with respect to location/direction from the Lake Tana.

MODIS EVI multi-temporal data provides ample opportunity to exploit the multi-temporal information required to discriminate these types of land features. Besides to employ multi-temporal data selecting appropriate classification algorithm that allows to use the full ranges of bands of multi-temporal data is also paramount importance.

In order to improve further the identification of croplands from the non-cropland ones, on the basis of the explained brief background the following image preprocessing steps have been followed. Taking the multi-temporal data and considering the dynamic nature of the study area, 16 day and 23 band MODIS EVI data was regrouped into 5 clusters of bands. Each cluster of bands allows to relate properly the EVI data with the actual surface condition more accurately

than the whole bands at a time. In each cluster of bands surface vegetation is explicitly characterized in a way that assigning of EVI threshold values for cropland and non-cropland could be possible. The temporal vegetation characteristic of land features were well established using local area knowledge, remote sensing data, field observation and other secondary information. Afterwards detail description of the surface vegetation condition of croplands and non-croplands is developed and presented in Table 2.

Table 2: Clustered bands based Enhanced Vegetation Index thresholds for cropland for selected sub-agro ecological region

Season Based Clustering of bands	Discrimination indicators	Upland East		Upland North		Upland South		Upland Moist East		Upland Moist South		Season	
		Cropped	Non-Cropped	Cropped	Non-Cropped	Cropped	Non-Cropped	Cropped	Non-Cropped	Cropped	Non-Cropped	Season (Months)	Rainfall Condition
1 (1-5 and 23)	Surface Vegetation	White & Bare	Slightly Green	White & Bare	Slightly Green	Slightly vegetated	Slightly vegetated	Black and Bare	Bare + Vegetated	Dark & Bare	Slightly vegetated	Mid-Dec to Mid-Mar	Very dry no rainfall
	EVI Range	0.05 – 0.38		0.06 – 0.37		0.09 – 0.48		0.06 – 0.43		0.10 – 0.46			
2 (6-11)	Surface Vegetation	Slightly Black & Bare	Slightly Green	Slightly Black	Slightly Green	Slightly vegetated	Slightly vegetated	Bare and black	Bare + Vegetated	Bare and black	Slightly vegetated	Mid-Mar to Mid-Jun	Small shower some places
	EVI Range	0.07 – 0.46		0.07 – 0.39		0.08 – 0.50		0.08 – 0.37		0.13 – 0.45			
3 (12-13)	Surface Vegetation	Slightly Green	Slightly Green	Slightly Green	Slightly Green	Water + Dense	Water	Dense and green	Dense and green	Dense and green	Dense and green	Mid-Jun to Mid-Jul	Heavy rainfall
	EVI Range	0.14 – 0.65		0.10 – 0.65		0.09 – 0.60		0.21 – 0.63		0.16 – 0.69			
4 (14-18)	Surface Vegetation	Deep Green	Deep Green	Deep Green	Deep Green	Grey vegetation	Light Green	Grey vegetation	Light Green	Grey vegetation	Light green	Mid-Jul to Mid-Sep	Heavy rainfall
	EVI Range	0.15 – 0.65		0.15 – 0.65		0.16 – 0.62		0.23 – 0.69		0.23 – 0.63			
5(19-22)	Surface Vegetation	Deep Gray	Deep Gray	Deep Gray	Deep Gray	Bare and white		Bare and white		Bare and white		Mid-Sep to Mid-Dec	Small rainfall
	EVI Range	0.09 – 0.48		0.12 – 0.49		0.13 – 0.47		0.12 – 0.50		0.16 – 0.55			

Source: - (Tibebe Kassawmar, 2013)

4.1.2 Sub-agro ecological region based assessment of Enhanced Vegetation Index thresholds for croplands

To discriminate croplands from the non-croplands (Table 3), the vegetation dynamics of croplands over the year was systematically characterized. Initially it was assumed that cropland within each major Agro Ecological Region (AER) would be represented by a single Enhanced Vegetation Index (EVI) threshold values. However, in due course of the data analysis, it was found out that within each major AER, there were pixels of cropland representing the non-cropland and vice-versa. Surface vegetation characteristics of cropland and non-cropland do vary significantly in time and space within each major-AER. For instance, in the lowlands of Lake Tana Sub Basin (LTSB), Fogera plain has distinct cropland vegetation dynamics compared to the Mecha and Dembia plains. As a result, thresholds developed for the entire floodplain didn't represent properly the actual situations. To overcome this problem, instead of using the full range of 23 MODIS EVI bands and determining the threshold of cropland, threshold setting for each AER for every cluster of bands has been found more accurate. This allows to focus which cluster of band or season of the year has greater separability of cropland from non-cropland. Detailed description is presented in Table 2. The detailed sub-division of AER in to sub units as well as re-grouping of EVI bands facilitated the identification and determination of EVI character of land features. As a result, criteria and rules to separate croplands became more specific to each sub-AER. For instance, specific cropland areas like flood recession and irrigation farms which look alike grass in the Eastern floodplain part are properly identified using this approach. Once the initial thresholds ranges of EVI values were identified, final values have been decided through iteration.

Table 3: Features of cropland and non-cropland

Cropland landscape elements	Non-cropland landscape elements
Irrigated (Small scale and commercial)	Forest
Rain fed	Settlement
Homesteads	Grassland
	Water body
	Bare land

4.1.3 Decision Tree Classification

In mapping heterogeneous landscape of Ethiopia like the Lake Tana Sub Basin (LTSB), single and straight mapping approach could not answer complex mapping problems. In setting the mapping criteria and rules, all the factors mentioned above guided to the more feasible classification approaches that support integrating multi-data in the classification process. In this regard Decision Tree (DT) based classification has been found relatively better to map complex landscapes than the ordinary supervised and unsupervised classifications. For that reason, the present study employed DT as mapping approach which allows to integrate several criteria in the classification. In order to develop the DT rules an intensive programming and writing syntaxes was required.

From the programming point of views, the Interactive Data Language (IDL) function shown below in Fig. 5 is declared as follows:

```
FUNCTION dt_cropvnoncrop,dt,data,aer
```

Where:

Function: the keyword used to create a function in ENVI IDL

dt_cropvnoncrop: the name of the function

dt: input parameter which is used as band identifier that tells the function on which band the function should execute

data: input parameter that accepts Moderate-Resolution Imaging Spectro-radiometer (MODIS) image

aer: input parameter to accept Agro Ecological Region (AER) image

The function first get the data size of the MODIS image and assigns it to a local variable called *info* as follows:

```
info = SIZE(data)
```

Then the function creates a temporary variable called *result* of type byte array with the size equal to pixel size of MODIS image to hold and return the result of the function as follows:

```
result = MAKE_ARRAY(/BYTE, SIZE = info)
```

The function implements the select case statement to easily identify on which band the comparison will be done based on the band identifier parameter (dt). Hence each case represents the bands of the MODIS image. Therefore, the functions checks the value of dt variable against list of cases and the function execution jumps to the respective case statement if a match is found and executes the statements found between *BEGIN* and *END* keywords within each case and returns the result.

```
CASE dt OF
1: BEGIN
.....
END

2: BEGIN
.....
END

.....

ENDCASE
```

In each case the minimum and maximum Enhanced Vegetation Index (EVI) threshold have been set for each AER using logical and comparison operators.

```
result += ((data GE 805 AND data LE 1813 AND aer EQ 1) OR (data GE 940 AND
data LE 2268 AND aer EQ 2))
```

For example the above code states that since the input data holds MODIS image which is a multi-dimensional array of pixel value, IDL built in capability iterates each array and checks if the pixel value of the image is between the specified ranges in the given AER and returns true or false or 1 or 0 value.

Therefore, when the function is called from Decision Tree (DT) it first checks the case statement and goes to the respective band identifier and it iterates for each pixel value of a given MODIS image data and finally it returns a mask (byte array) where the specified values in the input data are set to 1 and all other pixels are set to 0.

```
IDL - C:\Program Files (x86)\ENVI50\classic\save_add\dt_cropland_initial.pro - IDL
File Edit Source Project Run Window Help
Open New File New Project Save Cut Copy Paste Undo Back Forward Compile Run Stop In Over Out Call Stack Reset
dt_cropland_initial dt_cropland_initial dt_cropland_initial dt_cropland_initial dt_cropland_initial dt_cropland_initial dt_cropland_initial
FUNCTION dt_cropland_initial,dt,data,aer
info = SIZE(data)
result = MAKE_ARRAY(/BYTE, SIZE = info)
CASE dt OF
1: BEGIN
result += ((data GE 805 AND data LE 4313 AND aer EQ 1) OR (data GE 940 AND data LE 4768 AND aer EQ 2) $
OR (data GE 462 AND data LE 4022 AND aer EQ 3) OR (data GE 598 AND data LE 4260 AND aer EQ 4) OR $
(data GE 1021 AND data LE 4633 AND aer EQ 5) OR (data GE 455 AND data LE 3849 AND aer EQ 6) OR $
(data GE -151 AND data LE 5524 AND aer EQ 7) OR (data GE 772 AND data LE 3862 AND aer EQ 8) OR $
(data GE -12 AND data LE 5100 AND aer EQ 9) OR (data GE -12 AND data LE 4878 AND aer EQ 10) OR $
(data GE 840 AND data LE 3199 AND aer EQ 11) OR (data GE 780 AND data LE 2937 AND aer EQ 12) OR $
(data GE 176 AND data LE 4869 AND aer EQ 13) OR (data GE 628 AND data LE 3723 AND aer EQ 14))
END
2: BEGIN
result += ((data GE 673 AND data LE 4147 AND aer EQ 1) OR (data GE 769 AND data LE 4980 AND aer EQ 2) $
OR (data GE 642 AND data LE 4301 AND aer EQ 3) OR (data GE 802 AND data LE 3665 AND aer EQ 4) OR $
(data GE 1261 AND data LE 4522 AND aer EQ 5) OR (data GE 712 AND data LE 4618 AND aer EQ 6) OR $
(data GE 53 AND data LE 5794 AND aer EQ 7) OR (data GE 546 AND data LE 3375 AND aer EQ 8) OR $
(data GE -197 AND data LE 4896 AND aer EQ 9) OR (data GE 134 AND data LE 4576 AND aer EQ 10) OR $
(data GE 609 AND data LE 4286 AND aer EQ 11) OR (data GE 685 AND data LE 3854 AND aer EQ 12) OR $
(data GE 728 AND data LE 5026 AND aer EQ 13) OR (data GE 656 AND data LE 3881 AND aer EQ 14))
END
3: BEGIN
```

Figure 5: Bundle of IDL Function to map croplands

Table 4: Summary of iterated and final threshold values assigned for cropland in each sub-agro ecological region

Cluster of Bands	Sub-Agro Ecological Region													
	Midland South (1)	Upland South (2)	Water body (3)	Upland Moist East (4)	Upland Moist South (5)	Upland East (6)	Floodplain East (7)	Floodplain West (8)	Floodplain South (9)	Floodplain North (10)	Midland North (11)	Midland West (12)	Midland East (13)	Upland North (14)
Mid Dec – Mid Mar (1)	0.08-0.43	0.09-0.48	0.05-0.40	0.06-0.43	0.10-0.46	0.05-0.38	-0.01-0.55	0.08-0.39	-0.00-0.51	-0.00-0.49	0.08-0.32	0.08-0.29	0.02-0.49	0.06-0.37
Mid Mar – Mid June (2)	0.07-0.41	0.08-0.49	0.06-0.43	0.08-0.37	0.13-0.45	0.07-0.46	0.01-0.58	0.05-0.34	-0.02-0.49	0.01-0.46	0.06-0.43	0.07-0.39	0.07-0.50	0.07-0.39
Mid Jun – Mid Jul (3)	0.10-0.60	0.09-0.59	0.11-0.51	0.21-0.63	0.16-0.69	0.14-0.65	-0.01-0.61	0.08-0.43	0.003-0.56	0.03-0.54	0.08-0.57	0.09-0.53	0.07-0.60	0.10-0.65
Mid Jul – Mid Sep (4)	0.12-0.73	0.16-0.62	0.10-0.59	0.23-0.69	0.23-0.63	0.15-0.65	-0.05-0.56	0.05-0.57	-0.04-0.62	-0.05-0.65	0.12-0.59	0.14-0.56	0.04-0.58	0.15-0.65
Mid Sep – Mid Dec (5)	0.10-0.55	0.13-0.47	0.04-0.53	0.16-0.50	0.16-0.55	0.09-0.46	-0.05-0.51	0.09-0.46	-0.02-0.50	0.002-0.59	0.15-0.42	0.12-0.43	0.02-0.49	0.12-0.49

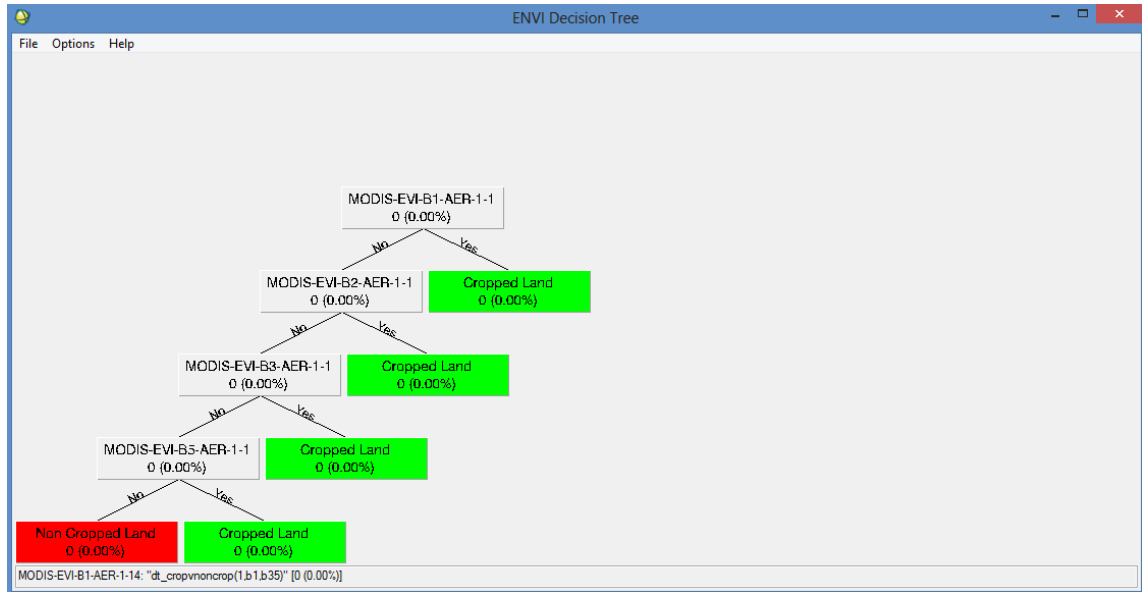


Figure 6: Decision tree with its criteria and rules employed to separate cropland from non-cropland

As displayed in Fig. 6 the criteria of separating cropland from the non-cropland was initially tested by the threshold values developed in Table 2. Using these thresholds, expressions for each sub-agro ecological region were assigned. The expressions work separately for each sub-agro ecological region and for each cluster of bands. Various rules applied to the classification algorithm that the present study applied has overwhelmed several shortfalls that different researches have encountered.

The Decision Tree (DT) is implemented as follows

All the tree nodes implement the Interactive Data Language (IDL) function stated above and each node represent each band of Moderate-Resolution Imaging Spectro-radiometer (MODIS), here band 4 is excluded from the DT since in this case it is not useful in separating cropland from the non-cropland. In defining each node the IDL function in the DT expression field is referred as follows:

dt_croplandnoncrop(1,b1,b35)

Where:

dt_croplandnoncrop: the name of the IDL function

(1,b1,b35) are input to the function that represent the band number, MODIS image and Agro Ecological Region (AER) image respectively. Running the set functions and rules in the DT window results in cropland map.

In general, though the procedure looks complex once the functions and rules are set properly it is very fast and very flexible for improvement. However, selecting thresholds and setting rules to run the Decision Tree (DT) algorithm was tiresome and complex. Nonetheless, applying the clustering of bands as well as Sub-AER based threshold setting and mapping has improved the mapping accuracy than taking the full extent of the study area and full range of bands.

Finally, the extracted cropland map was overlaid onto the Landsat Land-use/Land-cover (LULC) map and the overall accuracy was assessed. The accuracy assessment and the visual evaluation of the result between the derived cropland and the reference datasets from Landsat led to a conclusion that the applicability of MODIS based cropland mapping is promising for larger areas like Lake Tana Sub Basin (LTSB). The method applied to separate croplands from the non-cropland resulted in a promising output that could be used for several applications. The Output map produced is displayed in Fig. 7 Comparison of the result obtained from MODIS data was evaluated with Landsat product (Table 5).

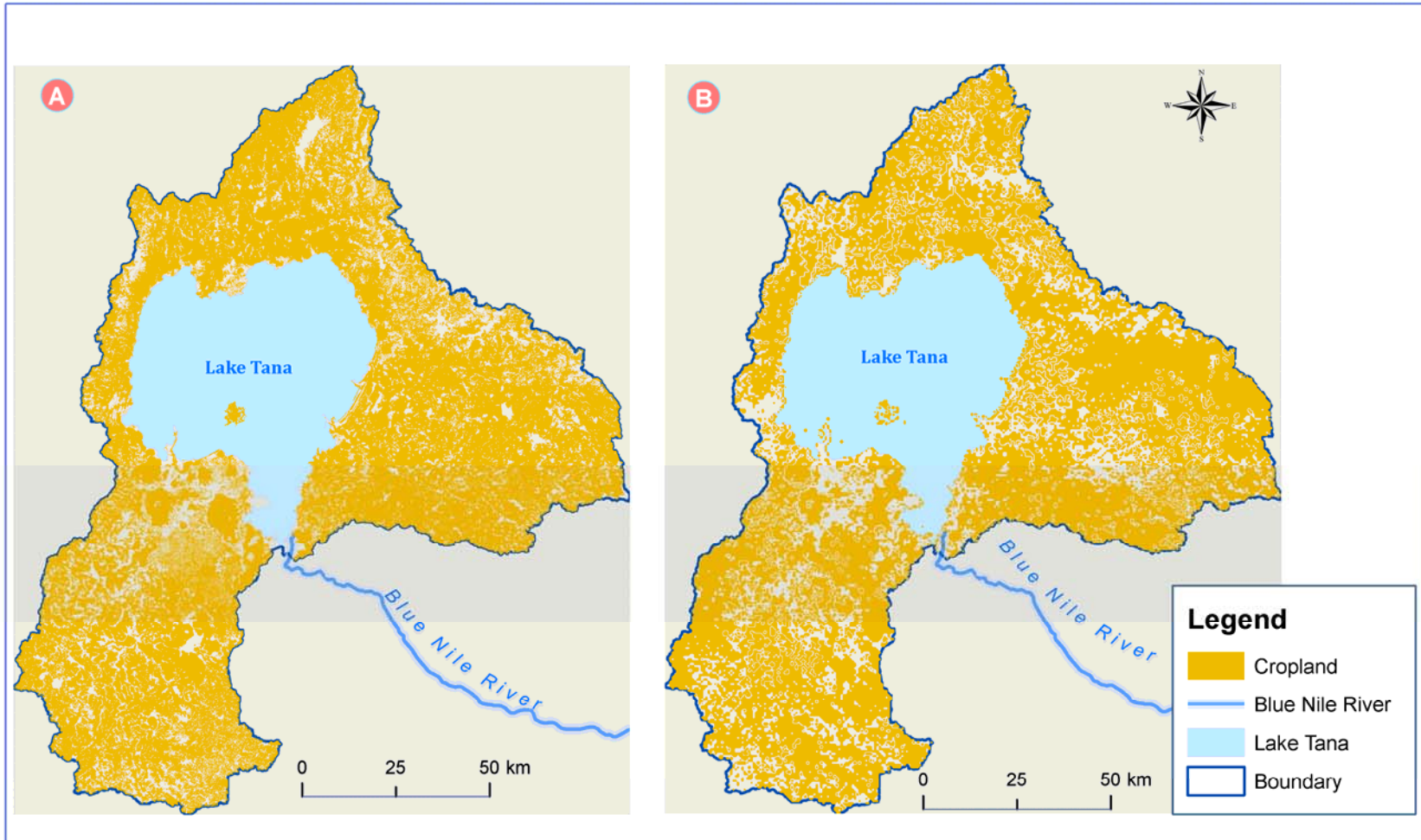


Figure 7: Cropland map of Landsat (A) and MODIS EVI data (B).

Table 5: Landscape mapping capability of MODIS EVI as compared with Landsat data

SN	Major AER	Area wise comparison								Estimation (for Cropland)		Type deviation of	Mapping Accuracy
		Landsat				MODIS				Landsat - MODIS			
		Cropland		Non-Cropland		Cropland		Non-Cropland		Area			
Area (km ²)	%	Area (km ²)	%	Area (km ²)	%	Area (km ²)	%	km ²	%				
1	Floodplain	1944.74	12.88	3842.84	25.45	2157.00	14.29	3630.58	24.05	-212.26	1.40	Over estimation	Good
2	Midland	2938.29	19.46	1509.36	10.00	3554.00	23.54	893.65	5.92	-615.71	4.07	Over estimation	Satisfactory
3	Upland	4219.17	27.94	643.78	4.26	3714.00	24.60	1148.95	7.61	505.17	3.35	Under estimation	Acceptable
	Total	9102.19	60.29	5995.98	39.71	9425.00	62.42	5673.18	37.58				Satisfactory
	Total (for LTSB)	15098.17				15098.18							

4.1.4 Accuracy of MODIS EVI data for cropland mapping

To evaluate the credibility of the map produced using the proposed methodology around 20 sample points for each sub-agro ecological region were randomly generated and an overall assessment was made. It has been found that the overall accuracy of the map was 75%.

The cropland area extent of LTSB estimated from Landsat based Land-use/Land-cover (LULC) map produced for the year 2013 covers 60% while MODIS based result revealed it is 62%. Comparatively, midland part of the basin has revealed bigger deviation than other parts of the study area. Where there is extensive cropland, Moderate-Resolution Imaging Spectroradiometer (MODIS) data estimates better. In addition, it has lower accuracy where there is abrupt topography and soil moisture variability which affect the spectral property of the earth surface. 4% of deviation from Landsat has been found in the rugged terrain and complex and mixed landscapes. Relatively, highlands and flat terrains have better accuracy than in the complex midlands. However, if the mapping approaches hadn't been implemented by region and multi-criteria based rules the error would be even more.

Comparatively, among the cluster of bands identified, as displayed in the table above, band cluster number 4 has little help to separate croplands from the non-croplands. In this period or season of the year all the cropland and non-cropland became equally vegetated and their spectral property in Enhance Vegetation Index (EVI) appears similar, as a result the possibility of discriminating land features is very difficult. For that reason, the data in this period were not used as major factor for cropland and non-cropland mapping. Contrary to that, cluster number 1 and 2 are bands that represent the driest season in the study area. In these periods, cropland and non-cropland do have distinct surface vegetation character as a result the EVI data range revealed strong separability of earth features. However applying initial threshold values for mapping croplands induced quite significant errors. This is due to the fact that within the considered Agro Ecological Region (AER), there still exist variation mainly related to the soil property as well as the land management practices such as flood recession based agriculture, irrigation based agriculture, and soil moisture residual based crop production.

From the findings of the cropland mapping it has been learnt that, in Lake Tana Sub Basin (LTSB) there are significant portion of land that farmers grow crops two to three times in a year on the same plot. For instance, in the lowland region, where soil moisture residual based agriculture is very common, Chickpea, Grass pea, vegetables and some oil crops grow after the

main cropping season. For that reason, the EVI value of these regions have been found greater in the drier seasons (January - March) than the wetter season (July - September). As a result, the EVI value is misleading if one considers only the major AER and season of the year without knowing the farming system. For that reason on top of vegetation characterization based threshold settings for major AER, Sub-AER based characterization which considers hydrology, soil property and the farming system of the area were very important that the present study employed.

4.2 Mapping potential extent of major crop types in Lake Tana Sub Basin

In Ethiopia, in general, and Lake Tana Sub Basin (LTSB) in particular, the actual areal extent of major crops has remained an information gap. In fact at various level, these data have been compiled and used for various purpose. However, credibility and appropriateness, of these data for any application is still questionable. The main reasons for futility of these data, among others are; lack of spatial explicit information that fits with the actual situation for example, land cover information compiled for administrative units (e.g. Kebele level) does not provide information on the specific distribution of the land cover classes within each unit. As a result land cover analysis for areas with delineations different from these units cannot be performed. To fill this important missing information, mapping potential cropland area as well as area extent of major crops at a watershed level are spring-boards and reasons for the realization of mapping crop types. In fact to map the potential area coverage of major crop types growing in the study area, mapping a cropland was a prerequisite. However, in the previous section, croplands were separated from the non-cropland ones. Above all the potential of multi-temporal data and its mapping approach was also well explored and elaborated in the previous section. In this section important considerations as well as challenges to identify and map major crops are presented and discussed.

4.2.1 Crop growing regions for major crop type mapping

As explained above, the approach employed to identify and map cropland and non-cropland landscapes, required sub-dividing major Agro Ecological Region (AER) in to sub-AER. Similarly, it has been also realised that dividing the cropland into different units where specific crop types are growing in specific regions is paramount importance for mapping different crop types. Initially, it was hypothesised that crop growth significantly vary only between major-

AER. However, it was recognised that crop growth doesn't follow conventionally distinguished rainfall pattern or crop seasons of the year. Hence, it was hypothesised that dividing the study area into regions could help a lot to identify crops and relate their phenology. Besides, the multi-temporal data combined with primary information on farming system could help a lot to represent the actual crop phenology.

Therefore, to better identify and map crop types using the proposed multi-temporal satellite data, apart from the developed AER (Hurni, 1986), and major and sub-AER, the study area was further sub-divided into smaller Crop Growing Regions (CGR). CGR in the context of the present study represent regions, where farming system, type of crops growing, altitude and rainfall are homogenous and thus the spectral behaviour of pixels in the satellite images have similar values (Fig. 8). The development of detailed CGR was based on existing Agro Ecological Region (AER), Digital Elevation Model (DEM), current framing system and secondary data collected from each Woreda Agricultural Office (WAO) of LTSB.

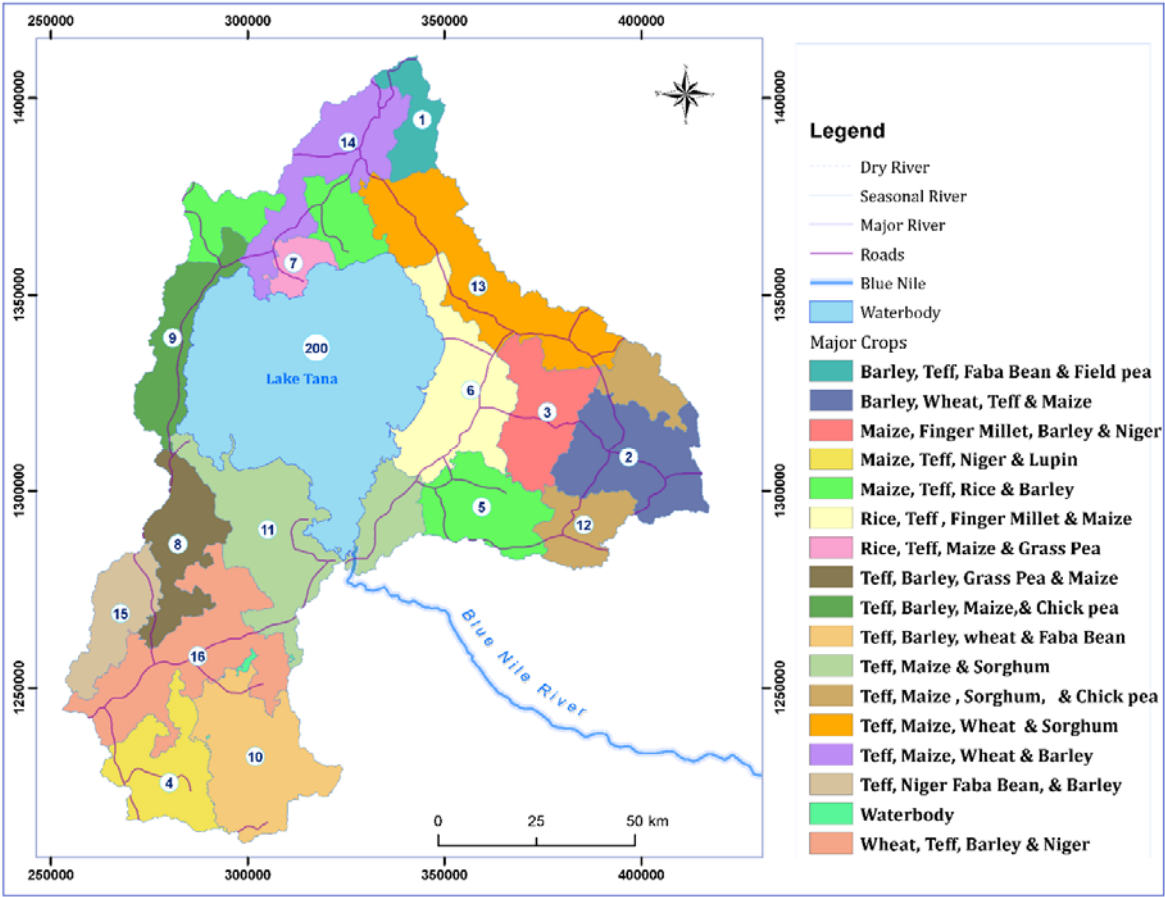


Figure 8: Crop Growing Region

4.2.2 Identifying major crops growing in Lake Tana Sub Basin

Identifying seasonally varying crop types growing in the study area by itself was not the main objective of the study. Rather in order to assess the ecosystem services and disservices, identifying and mapping dominant crop types could boost the assessment process. Ecosystem services assessment would be more practical if all types of crops growing in the region are considered. However for simplicity purpose rather selecting dominant crops is found to be practical. To select dominant crop types, taking Kebele as the smallest unit of analysis, several secondary information were collected including area covered by each crops, productivity, and yield. These factors were used to select potentially mappable crop types. Following that minimum of three to maximum of five dominant crop types were initially nominated for each CGR. However, during the assessment of mappable crops, more than one type of crops have been found with similar crop calendar that makes the identification and mapping process very complex. For instance, identification of Teff and Finger millet, Chickpea and Grass pea, Faba beans and Field pea have been found very difficult with the proposed methodology. For that reason they are treated as single crop type (Table 6).

Table 6: Major crop types identified in each crop growing region

CGR	Major crops							
	Teff and Finger Millet	Rice	Wheat and Barely	Sorghum	Maize	Faba bean and Field Pea	ChickPea and Grass pea	Niger
1	2		1			3		
2	3		1		4			
3	2		3		1			4
4	2				1			3
5	2	3	4		1			
6	2	1			3			
7	2	1			3		4	
8	1		2		4		3	
9	1		2		3		4	
10	1		2			4		
11	1			3	2			
12	1			3	2		4	
13	1			4	2			
14	1		4		2			
15	1		4			3		2
16	2		3					4

Note:-Rank is based on area coverage

Source: WAO, 2013

4.2.3 Characterising crop phenology based on traditional cropping calendar

Identifying and mapping crop types requires properly characterizing each crop phenology over their growing season. In Ethiopia, crop phenology data is not available at a required level and collection of the actual phenological property of crop types for such purpose demands at least one year which is very costly and become out of the scope of the present study. Nonetheless without having these data, crop type mapping is not possible. Hence, at the early stage of the study, a general information on Traditional Cropping Calendar (TCC) TCC in the context of the present study refers to a set of information on crops calendar, management and land use practices as well as temporal growth stage of crops. In the study TCC has substituted the actual crop phenology which was collected from the respective Woreda Agricultural Office (WAO) in the study area (summarised in Table 6). However, TCC fluctuates year after year following climate variability, farming practice change and technology adoption mainly for improved varieties. TCC often flexibly adjusted by farmers according to the dynamism of the above environmental factors. As a result getting accurate information of crop phenology from secondary sources is very difficult. Hence, besides to secondary data, primary information were obtained and compiled from local people (farmers). Farmers do have profound knowledge when they have to harrow their plot and plant a particular crop and periods of weeding, and harvesting at different condition. Hence, farmers' view on the temporal and spatial variability of crop calendar was instrumental for better refining the crop phenology obtained from WAO. These multi-source information of crop phenology simplified the process to develop relationship between actual crop phenology and remote sensing data.

Table 7: Summary of sample TCC over the year for major crops in Mecha woreda

Bi-Monthly	Teff	Finger Millet	Barley	Wheat	Faba Bean	Field Pea	Niger	Linseed
1	7	6	7	6	7	7	6	6
2	7	7	7	7	7	7	6	6
3	7	7	7	7	7	7	7	7
4	1	7	1	7	7	7	7	7
5	1	7	1	7	7	7	7	7
6	1	1	1	1	7	7	7	7
7	1	1	1	1	7	7	7	7
8	1	1	1	1			7	7
9	1	1	1	1	1	1	7	7
10	1	1	1	1	1	1	1	1
11	1	1	1	1	1	1	1	1
12	1	1	2	2	1	1	1	2
13	1	2	2	2	2	2	1	2
14	2	2	2	2	2	2	2	3
15	2	3	3	2	3	3	2	4
16	3	4	4	3	4	4	3	5
17	4	5	5	4	5	5	4	5
18	5	5	5	5	5	5	5	5
19	5	5	5	5	5	5	5	5
20	5	6	6	5	6	6	5	5
21	6	6	6	6	6	6	5	5
22	6	6	6	6	6	6	5	6
23	6	6	6	6	6	6	6	6
24	6	6	7	6	6	6	6	6
	1	Harrowing			2	Sowing		
	3	Germination			4	Vegetation		
	5	Flowering			6	Drying		
	7	Harvesting						

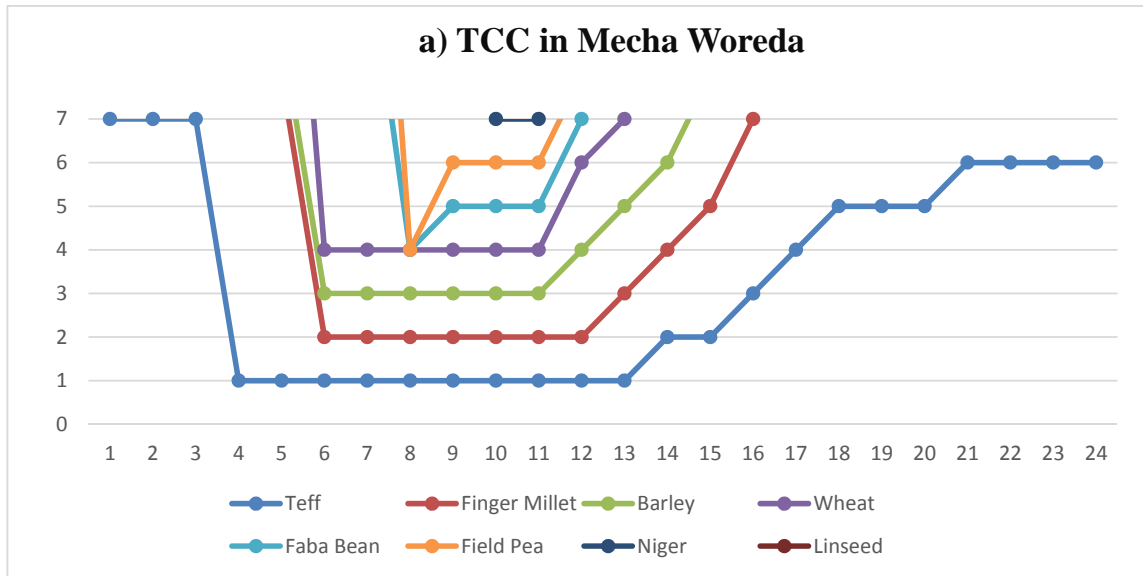


Figure 9: Summary of sample traditional cropping calendar over the year for major crops

In characterizing crops' phenology and relate TCC with the multi-temporal data, 12 months of the year were re-grouped into five major categories where crops phenology is supposed to be analogous. Compiling and refining TCC for 3-5 crop types in each of the 16 Crop Growing Region (CGR) was a prerequisite for proper crop type identification from satellite data. Sample TCC for one CGR is presented in Table 7 and Fig. 9. Similar kind of information were compiled for all the 16 CGR to finalize characterization of the crop phenology.

4.2.4 Matching traditional cropping calendar with Enhanced Vegetation Index (EVI) data

Having only the Traditional Cropping Calendar (TCC), it wouldn't be possible to map and know the spatial extent as well as the surface vegetation condition of crops growing in the study area. In order to do that, TCC which contains valuable information to identify and map crop types has to be linked with multi-temporal remote sensing data. However, the difficulty was finding the functional relationship between TCC and satellite data which is influenced by several factors. In fact, multi-temporal satellite data, particularly the 16 days Moderate-Resolution Imaging Spectro-radiometer (MODIS) Enhanced Vegetation Index (EVI) data, has been acknowledged by several researchers for its potential and valuable information to characterise crops' phenology. Initially, it was assumed that crops do have distinct spectral property which is observable within 16 day time that MODIS EVI multi-temporal satellite data can provide. In order to capitalize this information, to identify and map different crop types,

EVI values were carefully cross-checked with the TCC so that functional relationships could be established. TCC provides only temporal information of the crop phenology from harrowing till harvesting. Whereas, remote sensing data tells about the overall spatial and temporal plant phenology in terms of surface vegetation dynamics. In order to link these useful information, TCC was translated to surface cover vegetation describing parameters namely; harrowing, sowing, germination, vegetative, flowering, drying, and harvesting stages that every crops do have (Table 8).

Table 8: Traditional cropping calendar stages and their surface vegetation characteristics

SN	TCC phases	Surface vegetation characteristics	EVI information	Possible ranges of EVI values
1	Harrowing	Completely bare and exposed soil	Minimum EVI value	0-0.05
2	Sowing	Partly bare and partly vegetated depending on the crop type	Lower EVI value	0-0.015
3	Vegetative	Partly bare and partly vegetated depending on the crop type	Moderate EVI value	0.2-0.35
4	Flowering	Completely vegetated	Higher EVI value	0.2-0.35
5	Drying	Completely vegetated but not green	Moderate EVI value	0.02-0.15
6	Harvesting	Partially bare but not exposed soil	Lower EVI value	0.015-0.025

In order to do that, representative sample points (pixels) were picked from each Crop Growing Region (CGR) for each selected crops. Reliability of the picked sample point representing the actual crop type was cross-checked by both primary (ground survey) and secondary information Woreda Agricultural Office (WAO).

These points were used as Ground Control Points (GCP) by which the remote sensing based crop type mapping was done. On the bases of the selected sample plots CGR phenology was developed for each CGR and spectral profile for each crop types was developed. From the

spectral profile graphs representativeness of EVI temporal data was evaluated with the actual Crop phenology. If any GCP found wrong with TCC it was rejected and substituted by other sample points. Iteratively, doing similar steps of interrelating the TCC information (presented in Table 6) with the multi-temporal EVI data, threshold values were sorted out for selected crop types. In due course of action, it has been realised that the spectral behaviour of crops vary significantly from CGR to CGR and from season to season and from band to bands. For that reason, besides to dividing major AER in to sub units, clustering of bands was found to be very helpful. The 16 day MODIS EVI data was re-grouped in to 5 bands that properly characterize TCC

Afterwards, best representing bands of EVI data for each crop in each CGR was sorted out. Initially set threshold values of EVI data that represent a particular crop phenology were iterated till it provides better result. Finally best and representative thresholds of EVI value for each crop and crop phenology stage was determined. The table above depicts only one crop threshold values as sample, however, similar approach was followed to get threshold values for each crop growing in every CGR.

4.2.5 Decision tree for crop type mapping

In the previous section target crop types to be mapped were identified and their temporal phenology was properly characterised. The next step is to set decisive criteria, rules and function, and map each crop types. Decision Tree (DT) classifier was employed to finalize the mapping process. As an input only the cropland Enhance Vegetation Index (EVI) Moderate-Resolution Imaging Spectro-radiometer (MODIS) 16 day data was taken after masking it by the cropland map developed.

For every crop types, an independent DT was developed so as to reduce complexity of the mapping procedures (Fig. 10). In a particular Crop Growing Region (CGR), the function and expression rules set for mapping each individual crop types has been done initially by setting rules which determine where a particular crop is growing or not growing (Fig. 11). Once the probable crop growing region is determined by this rule, the next rule would be determining which particular pixel represent a candidate crop type. Based on initially identified threshold values selected for a particular crop in each CGR an initial map was produced. With the first trial map, the area covered by the candidate crop type was cross-checked for over and under

estimation taking the Woreda Agricultural Office (WAO) data as a reference. For every crop similar procedure was followed.

In due course of the mapping process, mapping one after the other and merging later after classification induced overlapping of crop types over one pixel. However the assumption was a single pixel represents one type of crop in one season. This assumption ignores double and triple cropping over the year that the present study didn't consider. Therefore, in such a mapping technique in order to avoid multiple representation of a pixel for more than one crop a mechanism was developed. Initially mapped region for a specific crop type was excluded for the next crop type mapping but used as a masking layer for the next crop type mapping. Once a pixel is assigned for one crop type it will never be considered for the next stage of classification. However, it was realized that this approach multiply the error induced at different stage if the first crop type was wrongly mapped. For that reason, initially less dominant as well as area specific crop types were mapped at the initial stage. Gradually more complex and dominant ones were mapped afterwards. The technique significantly (25%) improved the accuracy of classification in mapping major crop types growing in Lake Tana Sub Basin (LTSB).

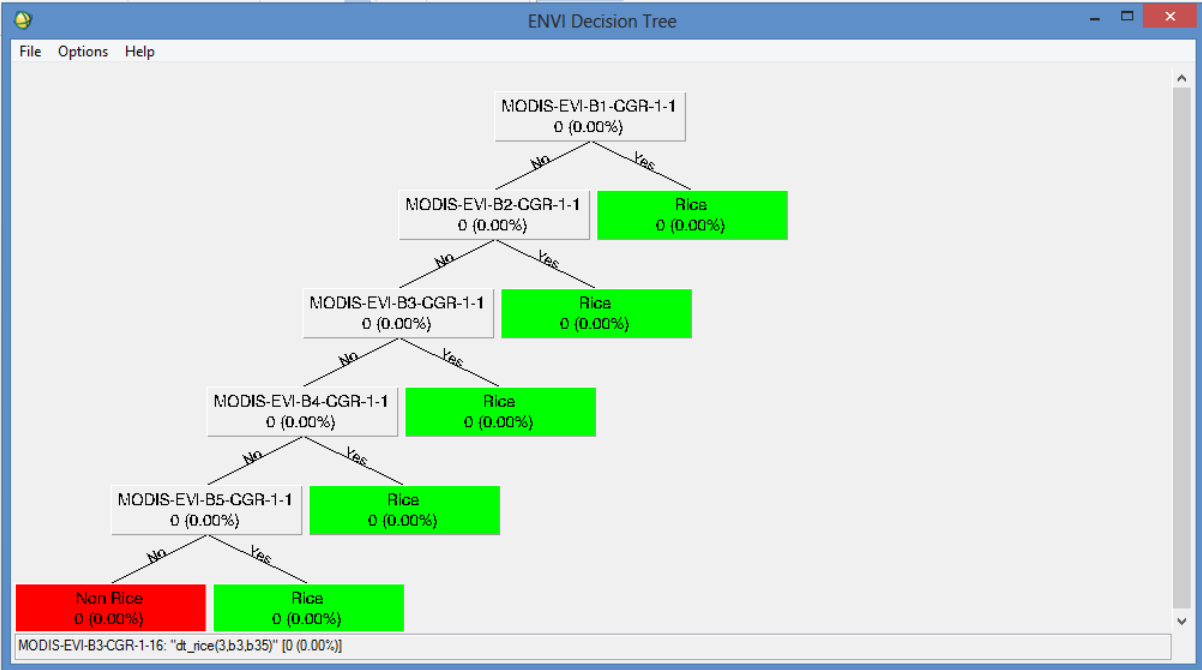


Figure 10: Decision tree with its criteria and rules employed to separate Rice croplands

```

FUNCTION dt_rice, dt, data, cgr
  info = SIZE(data)
  result = MAKE_ARRAY(/BYTE, SIZE = info)
  CASE dt OF
  1: BEGIN
    result += ((data GE 710 AND data LE 988 AND cgr EQ 5) OR $
              (data GE 519 AND data LE 924 AND cgr EQ 6))
    END
  2: BEGIN
    result += ((data GE 281 AND data LE 970 AND cgr EQ 5) OR $
              (data GE -507 AND data LE 907 AND cgr EQ 6))
    END
  3: BEGIN
    result += ((data GE 531 AND data LE 940 AND cgr EQ 5) OR $
              (data GE 560 AND data LE 5187 AND cgr EQ 6) OR (data GE 812 AND data LE 1988 AND cgr EQ 7))
    END
  4: BEGIN
    result += ((data GE 890 AND data LE 909 AND cgr EQ 5) OR $
              (data GE 209 AND data LE 4013 AND cgr EQ 6) OR (data GE 561 AND data LE 1271 AND cgr EQ 7))
    END
  5: BEGIN
    result += ((data GE 1184 AND data LE 1918 AND cgr EQ 5) OR $
              (data GE 404 AND data LE 841 AND cgr EQ 6) OR (data GE 525 AND data LE 907 AND cgr EQ 7))
    END
  ENDCASE
  RETURN, result
END

```

Figure 11: IDL functions and syntaxes to classify crop types (for Rice)

The Interactive Data Language (IDL) and the DT approach employed for each crop type works in a similar fashion as explained in section 4.1.3 except that for a crop type mapping Agro Ecological Region (AER) based mapping was substituted by Crop Growing Region (CGR).

Unfortunately, it was not possible to make standard accuracy assessment and cross-check the accuracy of crop type maps developed using the proposed methodology. The reason is it is very difficult to get reference data or map that could be used for such kind of assessment. The only possible way is ground survey of all the plots before the commencement of the next cropping season. This was not possible because of time and resource constraints. Nonetheless, indirect assessment have been scrutinised. Among which, comparison of area covered by a particular crop in a particular region that follows the administrative boundary was used (Fig. 12 & 13, Table 9).

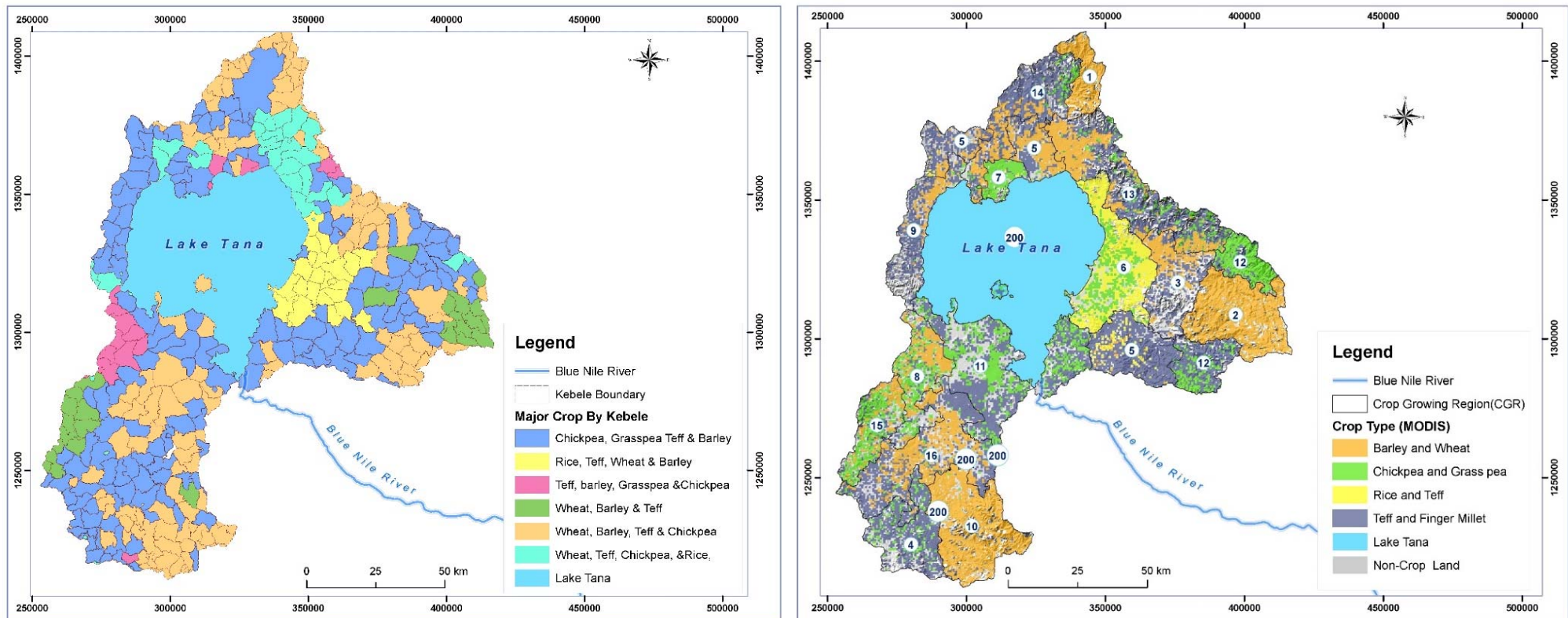


Figure 12: Major crop type map (A) at Kebele level from WAO, B) at Pixel level from MODIS data

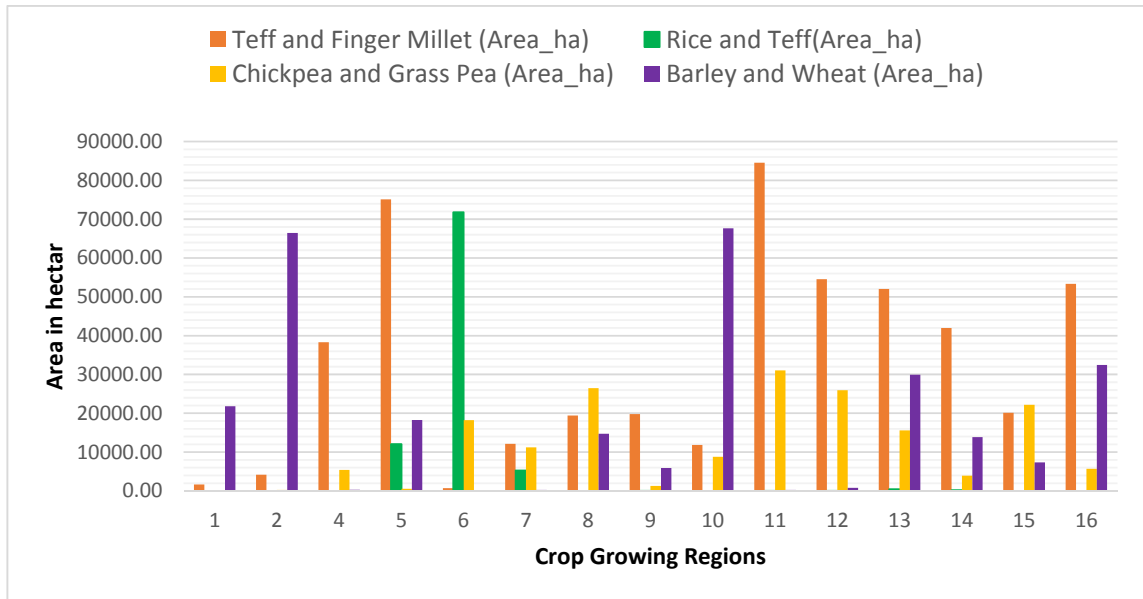


Figure 13: Area in hectare for major crop type (MODIS)

Table 9: Total area coverage (in hectare) of MODIS Crop by Crop Growing Region (CGR)

CGR	Teff and Finger Millet (ha)	Rice and Teff (ha)	Chickpea and Grass pea (ha)	Barley and Wheat (ha)
1	1683.39	0	73.87	21841.43
2	4175.79	0	289.13	66457.95
3	17891.51	182.6	220.62	12475.86
4	38304.39	0	5396.76	331.97
5	75130.48	12046.15	549.85	18260.93
6	694.76	71788.54	18227.89	207.65
7	12128.39	5261.07	11226.34	271.82
8	19432.79	0	26478.44	14745.58
9	19779.15	16.95	1277.28	5886.78
10	11828.99	0	8808.89	67677.13
11	84545.54	46.22	31054.83	277.76
12	54560.6	2.1	25930.75	777.95
13	52051.62	420.34	15604.38	29947.07
14	41973.87	182.43	3920.57	13858.98
15	20138.14	0	22197.66	7368.11
16	53356.16	0	5689.61	32460.54
200	Water body	Water body	Water body	Water body

4.3 Application area of mapping croplands and crop types

Assessment of ecosystem services and disservices on a particular area can easily be made if area coverage and type of crops growing in the region are mapped reasonably. In this regard, the present study findings indicated that, cropland and potential crop types growing in the region are properly mapped. Hence, regular assessment and monitoring of major ecosystem services could be materialized. Since the presented method employed multi-temporal data with high temporal resolution, it can easily be applied following the same procedure regularly. To highlight how such applications works a prototypical and simple ecosystem services assessment is done and presented. Even though ecosystem services and disservices are very complex issues that need several geospatial and non-spatial data, for simplicity purpose, a simple comparison over important and major ecosystem services and disservices namely productivity (crop yield) and erosion and sediment yield are selected. Since the central goal of the study is to depict how multi-temporal data can be processed using decision rule based classification and generate useful information for ecosystem assessment. Hence, a short brief and overview is presented below that portray how these kind of information can be generated and used.

4.3.1 Pixel based estimation of grain yield from croplands

One of the major ecosystem services that nature provides is grain produced from different crops growing over cultivated landscapes. These kinds of quantitative and spatially explicit information are useful to understand the very dynamic nature of cultivated landscapes. However, these important information are still not available at a required level for the fact that mapping the different crops is very difficult exercise. Besides, the ultimate information need to be generated is greatly affected by the dynamic nature of the cropping system that greatly varies over time. With this challenges, however, the proposed methodology has shown the potential of mapping cropland and potential crops growing in each developed Crop Growing Regions (CGRs). With this important data other information like area covered by a particular crop, potential yield and productivity of the area can further be estimated and mapped with reasonable accuracy.

In the above sections, potential area covered by major crops is estimated systematically. Taking this as an input data and integrating with other secondary datasets, it was tried to estimate grain production that each pixel of Lake Tans Sub Basin (LTSB) could provide. The grain production

was translated from a pixel information to an ecosystem service information using the following simple equation.

$$\text{Equation 1} \dots\dots\dots y = \frac{P \times 62,500 \times PCx}{10,000}$$

Where; y is estimated total yield of a crop (in quintal)

 P is the number of pixel counts that a particular crop is representing

 PCx is productivity of a particular crop x in q/ha for each CGR collected from WAO

 62, 500 and 10,000 are constants to convert pixel number and area to hectare.

Once pixel based spatially explicit quantitative information of potential grain production for a particular crop is estimated it would be possible to make spatial comparison of the ecosystem service provided from a particular region.

The approach has several advantages compared to the usefulness and quality of the data available so far. Compared to the conventional methods, firstly, it allows to get such information at pixel level. Pixel level data allows to locate and understand the spatial variability of area coverage and grain yield of a particular land use practice. Secondly, it allows to translate the information from administrative level to watershed level and vice versa. These two major advantages of the approach makes the ecosystem assessment very flexible and spatially explicit.

As far as concerning the accuracy of the information, even though it is very difficult to make proper accuracy assessment for such applications, the accuracy of ecosystem services still related to the accuracy of crop type maps. Nonetheless, in order to get a clue how the data is accurate, the estimated grain for a particular crop in a particular region was cross-checked with the data obtained from WAO. Since the data collected from WAO is Kebele level, it would be meaningful to compare the grain yield information estimated from MODIS data with the WAO data. Woreda level comparison assessment was made and presented in Table 10 and 11 below.

Table 10: Sum of total area (Hectare) of crop type using MODIS data

S.No	Crop Type	Area (Hectare)
1	Teff and Finger Millet	510131.16
2	Rice	90474.12
3	Chickpea and Grass Pea	178073.28
4	Barley and Wheat	293812.20

Source: MODIS Data

Table 11: Sum of total area (Hectare) of crop type using WAO data

S.No	Crop Type	Area (Hectare)
1	Teff and Finger Millet	580136.58
2	Rice and Teff	110416.19
3	Chickpea and Grass Pea	198079.00
4	Barley and Wheat	323856.20

Source: WAO Data

Concerning to the availability of similar information at the country level, there are two different data sources which refer the same issue. One is from the Ministry of Agriculture and the other is from Central Statistical Agency. Both of the government institutions collect and compile the data following different approaches at different scale.

Comparing the information scale that the country has, the Ministry of Agriculture (MoA) collects data at Kebele level while Central Statistical Agency data is at Zone level. Downscaling and up scaling of these different scale data has remained a challenge for several development endeavours and research activities. Therefore, with all its drawbacks pixel based information is still helpful for several applications.

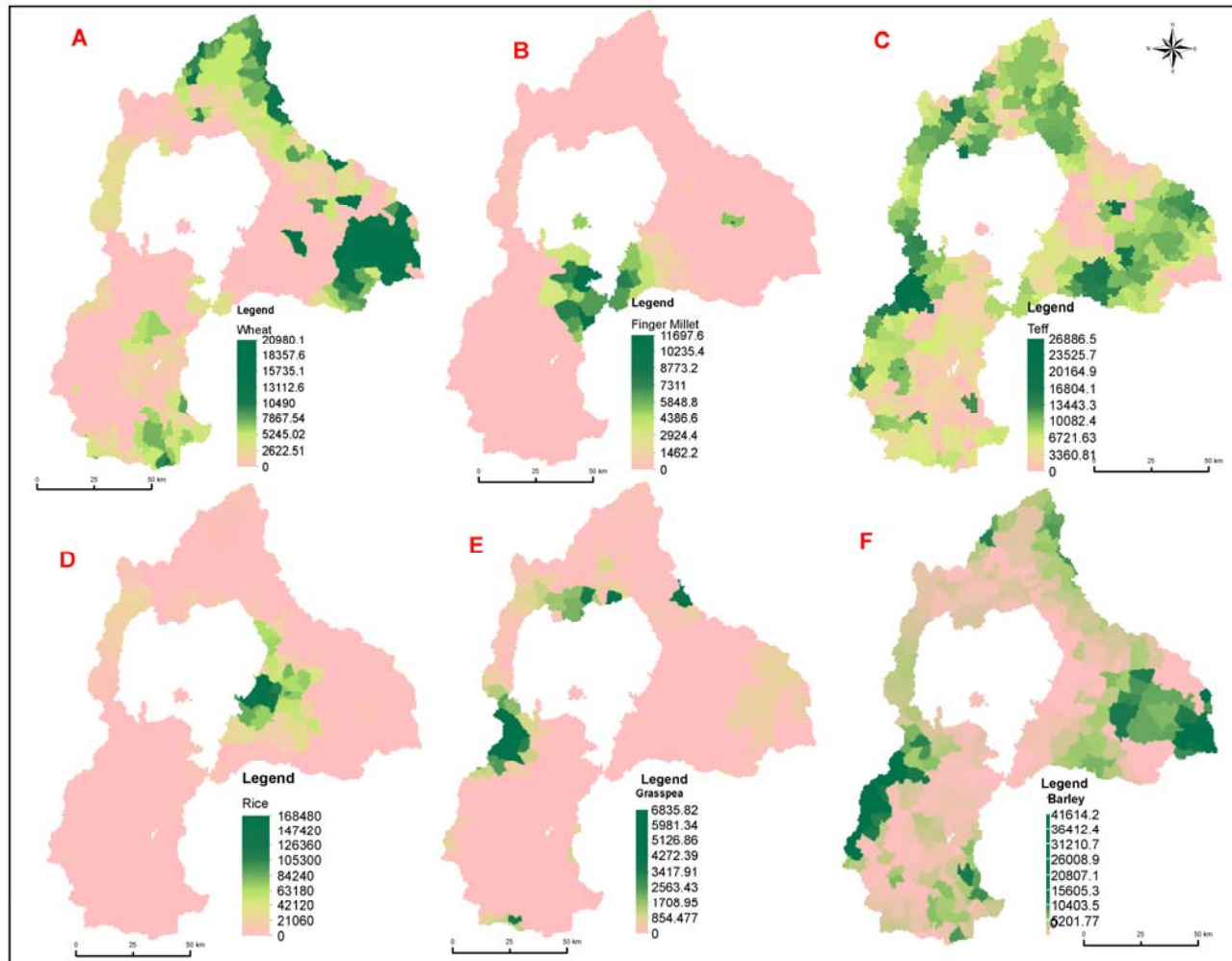


Figure 14: Production map by each crop type (Source WAO)

4.3.2 Surface vegetation dynamics of cropland

In most of the times when we make assessment of ecosystem services and disservices, the dynamic nature of cropland is commonly overlooked. Rather it is generalized by the conventional assumption that cropland are cultivated fields and have similar surface cover condition. However, in reality surface cover vegetation condition of cropland exhibit all types of surface cover over a single growing season. Interestingly, this dynamic nature of cropland over one crop growing season varies with the land use practices and crop phenology. In relation to remote sensing data, croplands are bare lands during harrowing phase, appear wetlands during sowing phase, also appear like grasses during the germination and vegetative stage and slightly also resemble forest landscapes at their flowering and before harvesting phase. In all these phases of the crop phenology, they are having distinct ecosystem services and disservices (Tibebu Kassawmar, 2013).

In regard to the assessment of the overall ecosystem services and disservices, quite many researches implemented on estimation of biomass production, soil loss and sediment yield, the dynamic nature of cropland is not properly estimated. The common reason for the exclusion of these important information in the analysis could be attributed to a couple of issues, on one side the available assessment techniques ignore these attributes; on the other side, the techniques to quantify and generate these kind of highly dynamic information is very difficult (Tibebu Kassawmar, 2013). In order to address these research gaps, especially for the latter case, the present study has developed a simple vegetation characterization methodology for cropland separately. However, in order to properly characterize the vegetation condition of croplands, a prerequisite is to have accurate cropland separated from the non-cropland ones. However, in sections above cropland along with major potential crop types are already mapped.

Once the types of crop growing in the study area are identified and mapped it was possible to associate and characterise surface vegetation condition of each pixel represented by a specific crop type at different season of the year. The assumption was surface vegetation cover of cropland can be characterised by the phenological order of crops growing over the cropland. For this particular purpose, three measurement indicators were assumed; Bareness, Greenness and Greyness.

To characterise the vegetation dynamics of croplands over time and space, a systematic methodology was formulated (see the table and graphs below). Based on the developed cropland vegetation characterization scheme, individual crop map was taken and the 16 day Enhanced Vegetation Index (EVI) Moderate-Resolution Imaging Spectro-radiometer (MODIS) data was masked to exploit the full range of multi-temporal information contained in the original pixel value. Initially, every crop phenology stage was represented by appropriate surface vegetation condition indicators over a single crop growing season. Later, crop phenology and EVI data were cross-linked to characterize the vegetation condition. Finally every pixel value was translated to vegetation condition indicators. In order to better capitalize the full range of EVI multi-temporal data, the three major indicators were further sub-divided in to two sub-categories. Bare to Full Bare and Half Bare, and Green to Full Green and Half Green and Grey to Half Grey and Full Grey. Eventually, every pixel values were replaced by the vegetation cover indicators. In the process of assigning of these indicators to every pixels was done with due consideration of variability of crop phenology in each Crop Growing Region (CGR). In this regard, the Traditional Cropping Calendar (TCC) information compiled for each CGR was very helpful. This allowed to get better surface vegetation condition for every crop. Finally, pixels with similar vegetation conditions were re-merged regardless of the crop types which gives cluster of bands of homogenous vegetation condition for the entire study area.

The criteria and vegetation characteristics of the vegetation indicators for each cluster of bands was summarised in Table 12. The table helps to match crop phenology and surface vegetation condition with EVI data. The presented information in the table varies with crop types and CGR. Therefore, similar representation and analysis was done for all the CGR and for major crop types

In fact crops which have extended growing period do have longer period vegetated landscapes. For instance, Finger millet, Sorghum and Maize have relatively long period vegetated landscape than wheat, Beans. The land use practice follows the crop type growing in a particular pixel. This also varies in time and space in each CGRs. Therefore, leaving aside this very complex nature of the croplands, at least the present study took four major crops and tried to characterise the vegetation cover dynamics of the cropland.

Table 12: Indicators and proximate vegetation characteristic over time and space (for Teff and Finger Millet)

S N	Major- Indicators	Sub- Indicators	Vegetation Characteristics Description	EVI Band Range	Proximate Season of the year	Initially proximate estimated surface vegetation cover (%)
1	Bareness	Full	-Pixels with no vegetation and dry soil	23and 1-12	Mid December – Mid June	0
			-Represents completely bare surface with no biomass			
		Half	-Pixels partly bare and partly vegetated on moist soil	13-14	Mid June – Mid July	0
			-It represents partly sowing stage of the crops and germination on saturated soils			
2	Greenness	Half	-Pixels partly bare and partly vegetated	15-16	Mid July – Mid August	20
			-Represents the sowing and germination stage of crops phenology			
		Full	-Pixels completely vegetated	17-19	Mid August – Mid October	100
			-Represents the rigorous growth and flowering stage of crops			
3	Greyiness	Half	-Pixels partly dry and grey vegetation	20-21	Mid October – Last November	100
			-It represents the maturity of crops phenology			
		Full	-Pixels completely dry vegetation	22-23	Full December	20
			-It represents the full harvesting stage of crops phenology			

For each cluster of EVI data, on the basis of the crop type maps and in reference to each crop phenology behaviour initial threshold values of EVI data that represent bareness, greenness and greyness was produced and presented in Table 13. After a successive and iterative crosschecking amendments were made and best representative thresholds were selected and presented below.

Table 13: Season based range of EVI values for each vegetation indicators

EVI original bands	New EVI Cluster of Bands	EVI Value for each VI					
		Bareness full	Bareness half	Greenness half	Greenness full	Greyness half	Greyness full
1-5 and 23	1	-0.0697-0.1264	0.1264-0.1583	0.1583-0.1896	0.1896-0.2337	0.2337-0.3087	0.3087-0.5524
6-11	2	-0.0975-0.1278	0.1278-0.1697	0.1697-0.2092	0.2092-0.2506	0.2506-0.3036	0.3036-0.5409
12-13	3	-0.1020-0.1760	0.1760-0.2494	0.2494-0.3141	0.3141-0.3735	0.3735-0.4340	0.4340-0.6878
14-18	4	-0.0966-0.1346	0.1346-0.2619	0.2619-0.3398	0.3398-0.4015	0.4015-0.4595	0.4595-0.7311
19-22	5	-0.1189-0.1114	0.1114-0.2102	0.2102-0.2502	0.2502-0.2871	0.2871-0.3329	0.3329-0.5612

The new Cluster of MODIS band is developed in relation to the major crop phenological phases and Cluster 1 is supposed to be the dominant Harrowing phase for dominant crops 2- Harrowing and sowing, 3- Sowing, 4- Vegetative, 5-Drying and harvesting. Based on the assigned vegetation condition indicators, area wise comparison of cropland vegetation was calculated and presented in Table14.

Table 14: Vegetation condition of cropland over five major crop phenology stages

Crop phenology stages	Bareness full		Bareness half		Greenness half		Greenness full		Greyness half		Greyness full	
	Area (km ²)	%	Area (km ²)	%	Area (km ²)	%	Area (km ²)	%	Area (km ²)	%	Area (km ²)	%
1	1346.42	14.29	2908.20	30.86	374.37	3.97	134.16	1.42	1741.23	18.47	3031.60	32.17
2	1310.28	13.90	1979.33	21.00	1421.65	15.08	414.47	4.40	2121.91	22.51	2288.35	24.28
3	892.77	9.47	1293.11	13.72	2140.69	22.71	1302.50	13.82	2159.81	22.92	1747.10	18.54
4	89.41	0.95	897.37	9.52	2959.75	31.40	1553.27	16.48	2543.91	26.99	1492.28	15.83
5	67.25	0.71	1159.00	12.30	2051.87	21.77	708.13	7.51	3012.14	31.96	2537.60	26.92

The period between December and April is assumed to be time of total bareness. However, in the period between December and April LTSB about 5% of cropland revealed greenness. These vegetated landscapes are pixels that represent irrigated fields and flood recession based crop cultivation. In this period, pixels that are represented by Greenness indicators, both full and half, do not exist in the mid-land and upland regions of Lake Tana Sub Basin (LTSB). However, there are still some pixels remained green that commonly grow after rainfall stops. These crops include Chickpea, Grass pea and other oil crops. Because, these crops need little soil moisture to complete their growth stage. However, they are commonly growing on flat terrains of the landscape than the mid and highland. On the contrary, in this period more than 45% of cropland of LTSB is devoid of vegetation. This part of the cropland is being harrowed and disturbed by ploughing due to field preparation for the next plantation season. Whereas 50% has revealed undisturbed surface with some plant residue left over the fields. These fields are again become disturbed and exposed soil in the next phenological stage of crops (Fig. 15)

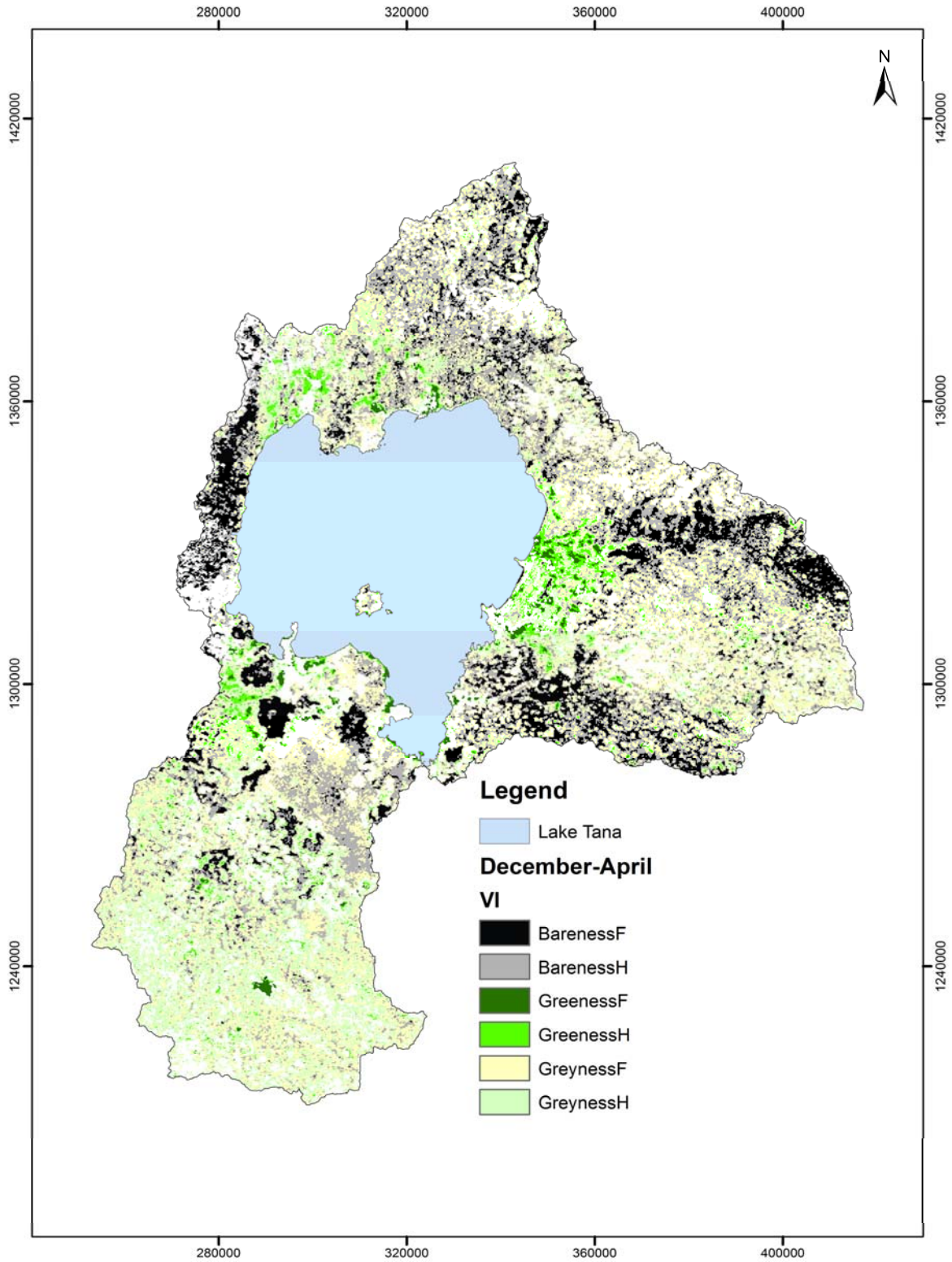


Figure 15: Vegetation condition of cropland between December-April

The period between April and June is the time when early rainfall is expected though it is assumed to be remained dominantly bare (Fig. 16). As a result, croplands are commonly experiencing slight vegetation initiation for short period till farmers start the actual sowing of some crops like Maize, Finger Millet and other long growing period crops. For that reason, areas that receive early rainfall revealed slight vegetation coverage. The result shows that around 20% of cropland is vegetated in this period. Location wise, greenness is very common in the mid and upland portion of the area compared to the floodplain part of the region. In fact for some pixels, which appeared greener in both two periods, the reason could be wrongly assigned pixels which represent either forest or grass landscapes. However, more than 35% of the region is devoid of any vegetation.

Especially it is dominated in the floodplain portion of LTSB. The reason could be attributed to an intensive harrowing of croplands well as complete removal of plant residues left over the crop fields.

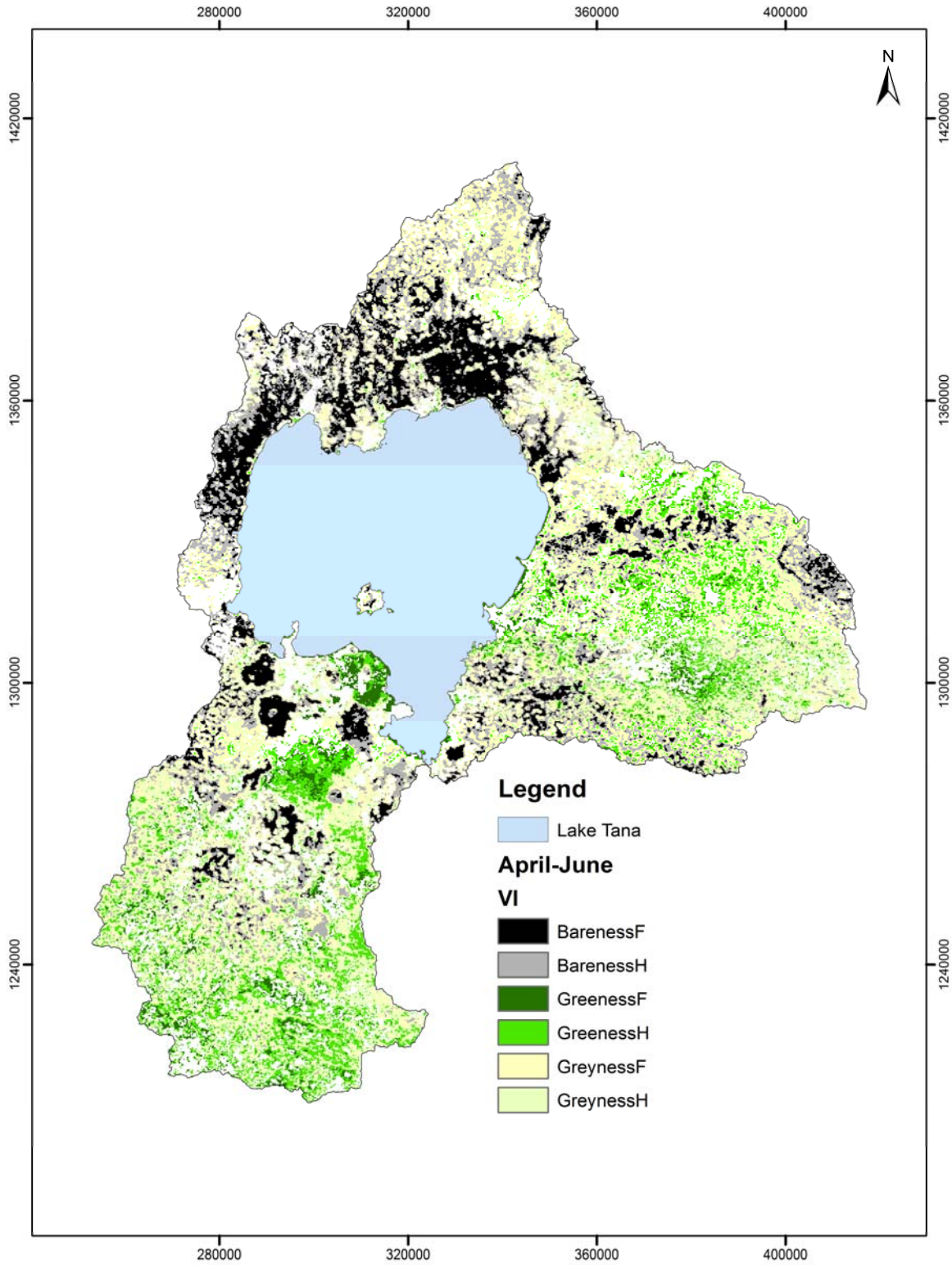


Figure 16: Vegetation condition of cropland between April-June

This part of the cropland is being harrowed and disturbed by ploughing due to field preparation for sowing. The period is characterised by half bareness and half wetness. Whereas 46% has revealed undisturbed surface with some plant residue left over the fields. These fields are again become disturbed and exposed soil in the next phenological stage (Fig.17).

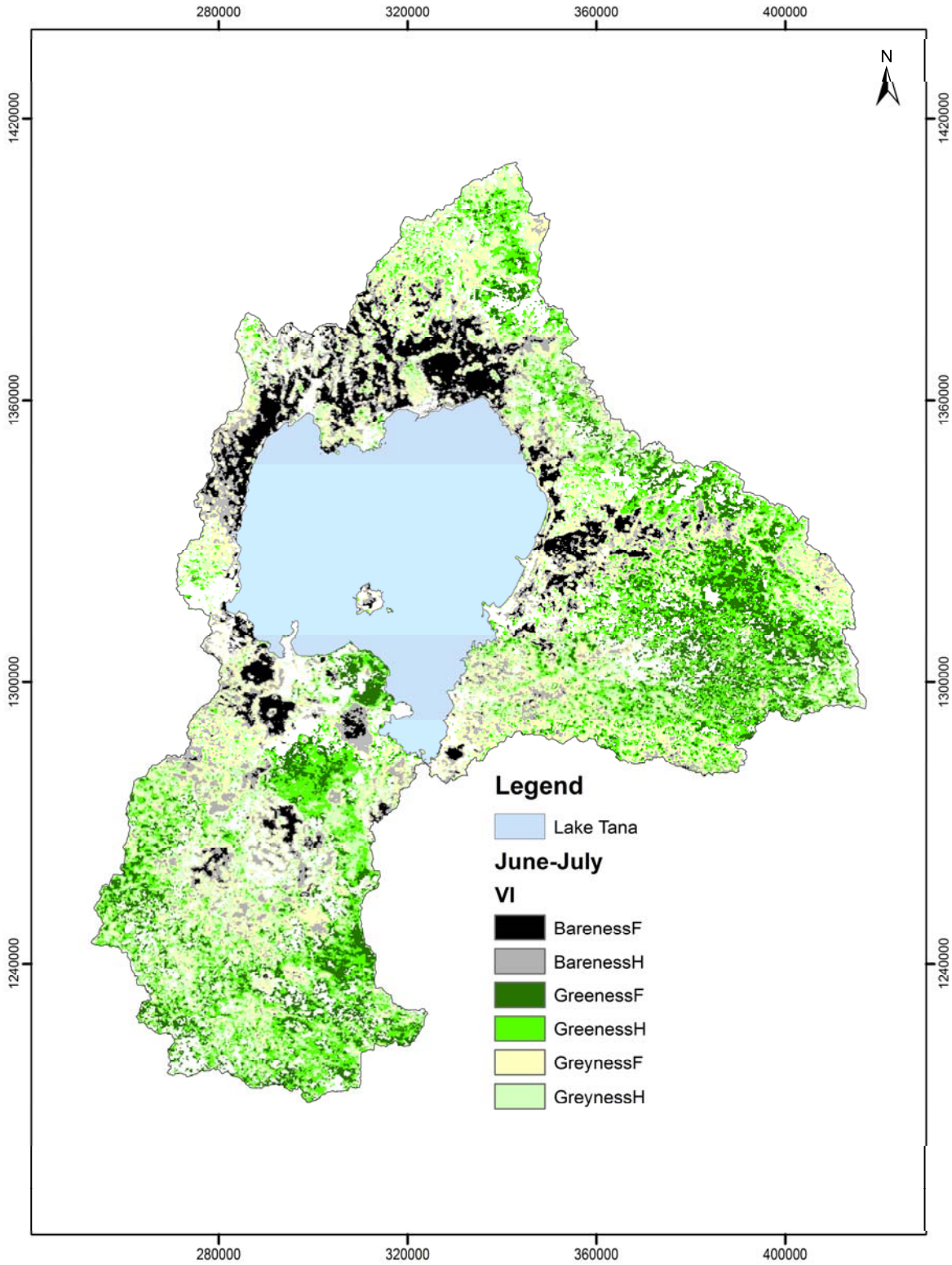


Figure 17: Vegetation condition of cropland between June-July

The period between July and October is the time when almost all croplands become fully vegetated (Fig. 18). It is considered as period of complete greenness. Other than some insignificant portion of the region where there are few fields being harrowed and/or fallowed for some purpose, all croplands are covered by crops that explains with their vegetative and flowering stage. Around 70% of the area are completely vegetated. The reason why there is greyer and bare in this period is on one side, in this period, especially around the floodplain, where Teff is dominantly growing it appeared that Teff and rice fields are both pulverized and planted. As a result, they appeared like neither bare nor vegetated. It is due to overflow of water on cropland. However, these pixels again appeared greener in the next phase when flooding is gone and rain fall stops. Otherwise less than 10% of cropland of LTSB appeared bare. If we look at these pixels, it represents wetlands which are remained flooded and completely submerged by water even farmers use them for crop growing after flood recession. In addition to flooding, there are also some field plots which revealed lower vegetation cover which is probably representation of harvesting of early maturing crops like Barely and other improved varieties with short growing periods.

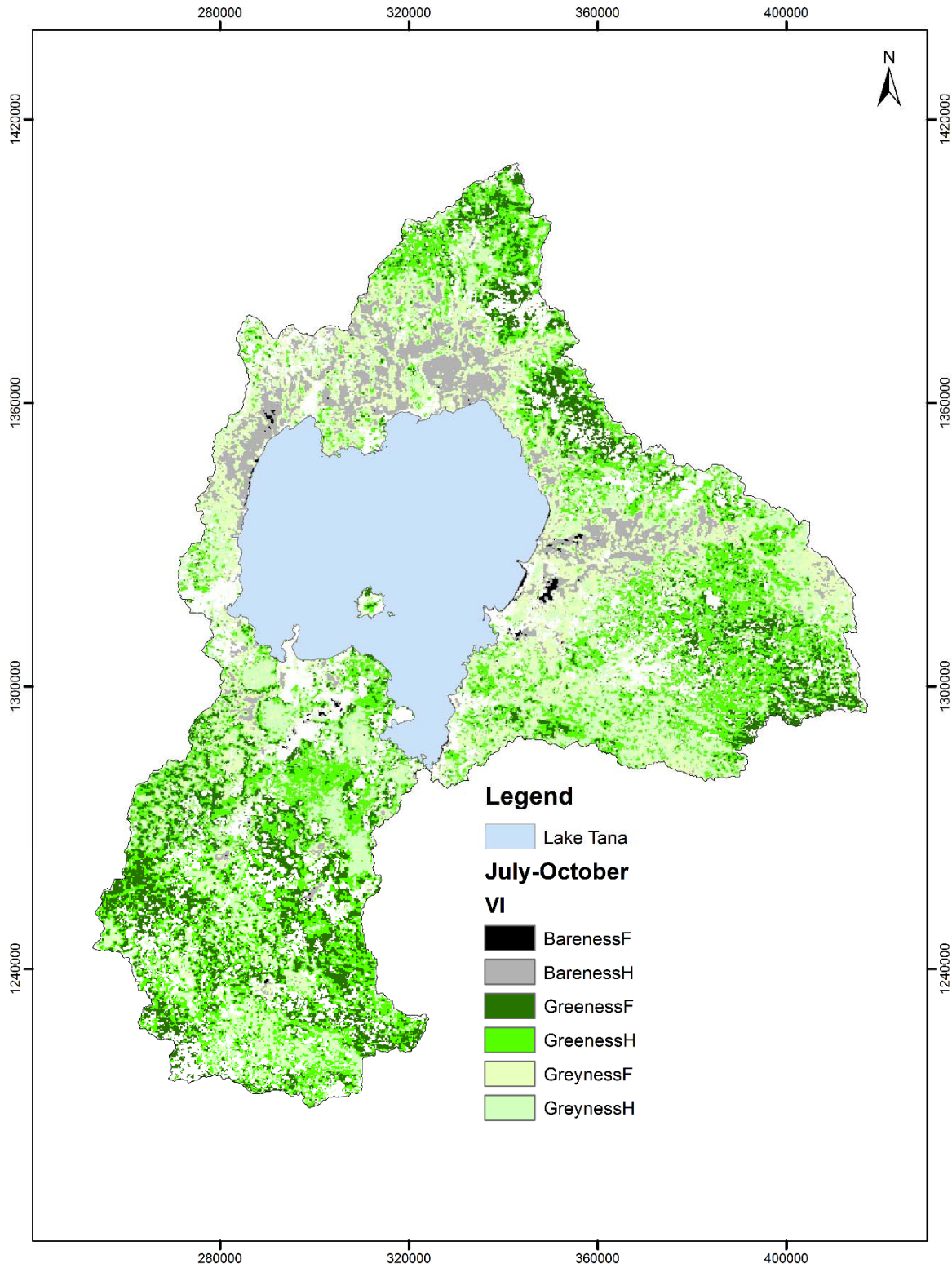


Figure 18: Vegetation condition of cropland between July-October

The period between October and December is the time when almost all crops become fully matured and harvested (Fig. 19). As a result it is considered as period of greyness. It represents 57% of the area. However, crops that either yet need to be planted or need longer period for harvest, are still there and cover 27% of the landscape. The majority of greenness is observed in the floodplain region of LTSB. Greenness of this portion of the region is higher in this period than the previous. In the mid and uplands, besides to some greenness, there is still huge plant matter left over the field. Otherwise less than 10% of cropland of LTSB appeared bare. This is a transition between greyness to bareness.

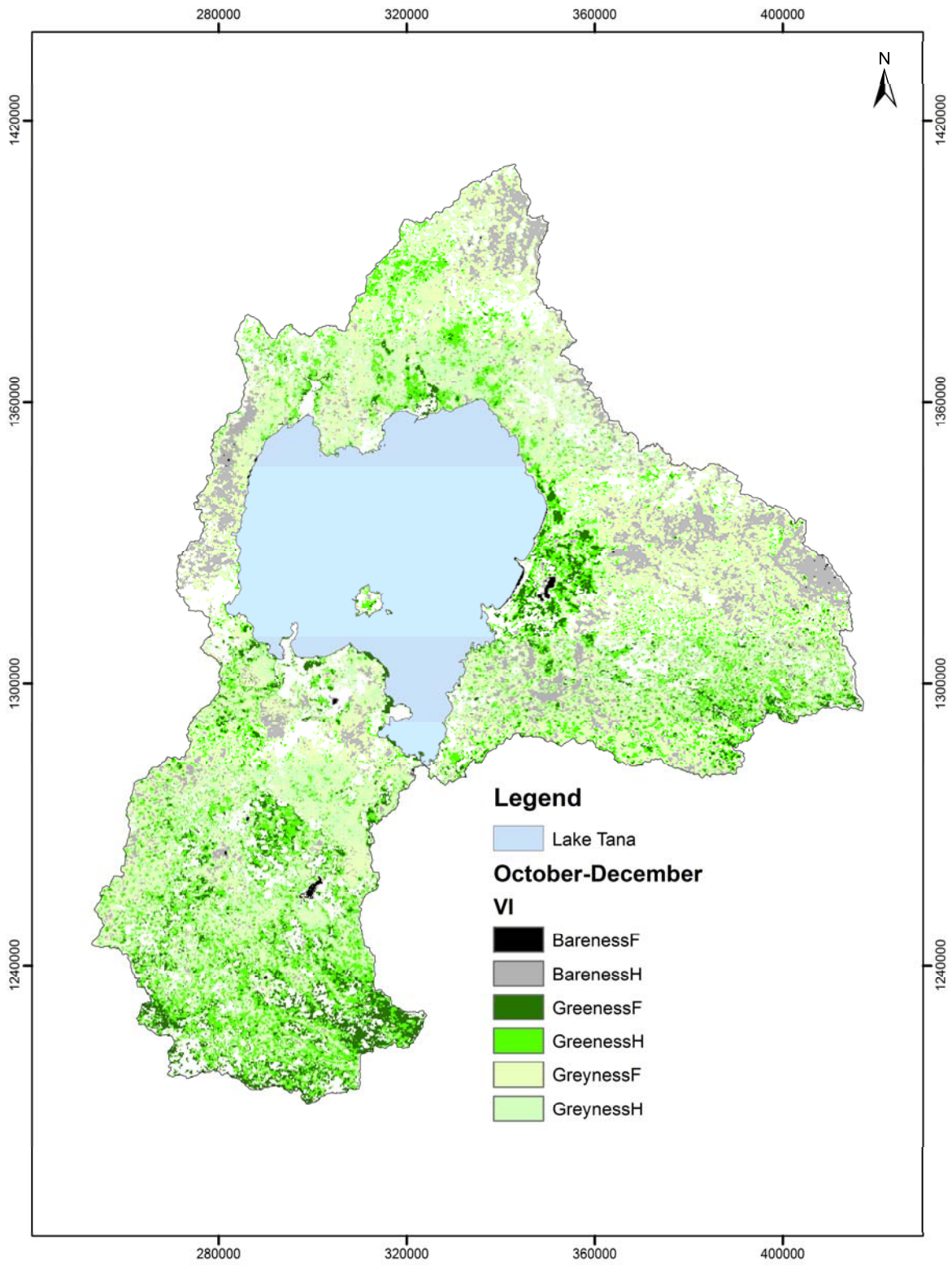


Figure 19: Vegetation condition of cropland between October-December

4.3.3 Surface cover vegetation of croplands in relation to soil erosion risk

Knowing the spatio-temporal vegetation dynamics of cropland could help to know and estimate some of the major ecosystem disservices mainly soil erosion and sediment yield. In the previous section, multi-temporal remote sensing data based vegetation index maps are developed which can be used to make comparative assessment on the level of erosion risk over a particular growing period. Essentially, different landscapes covered by different crops do have distinct erosion risk over the crop growing period. Among the other factors which determine soil erosion risk, the temporal variation of vegetative growth of crops in relation to the rainfall pattern over the season determine the level of soil loss. Therefore, relating the crop phenology and land use practice and estimating level of erosion makes the ecosystem assessment more realistic. In order to do that, at this final stage of the analysis, using pixel based Enhanced Vegetation Index (EVI) values which are already translated to vegetation conditions are ranked on the basis of their surface vegetation condition which depict soil erosion risk. The methods are presented and discussed below.

By linking the crop phenology and land use practices with the most important erosion factor (rainfall) that conditioned the surface vegetation of croplands, an attempt was made to rank erosion risk of croplands. To rank erosion risk level of croplands, the periods when as well as the landscapes where high erosion risk is expected are initially identified. In this regard, in relation to erosivity of rainfall (to trace when it occurs), the period between Mid-September to March has negligible soil erosion risk. During this period (the driest over the year in the study area) there is little rainfall (see Figures 20 and 21) and therefore little to no erosion by water occurs. After harvesting soil erosion is very low due to less rainfall. On the other hand, to trace where it occurs, considering the crops phenology and land use practices, the erodibility of croplands is high when the land is harrowed and at the stage of sowing. Besides to these two justifications to exclude the erosion damage time and conditions, local area knowledge and other secondary data, like Agro Ecological Region (AER) and Crop Growing Region (CGR) were helpful to interpret and rank soil erosion risk.

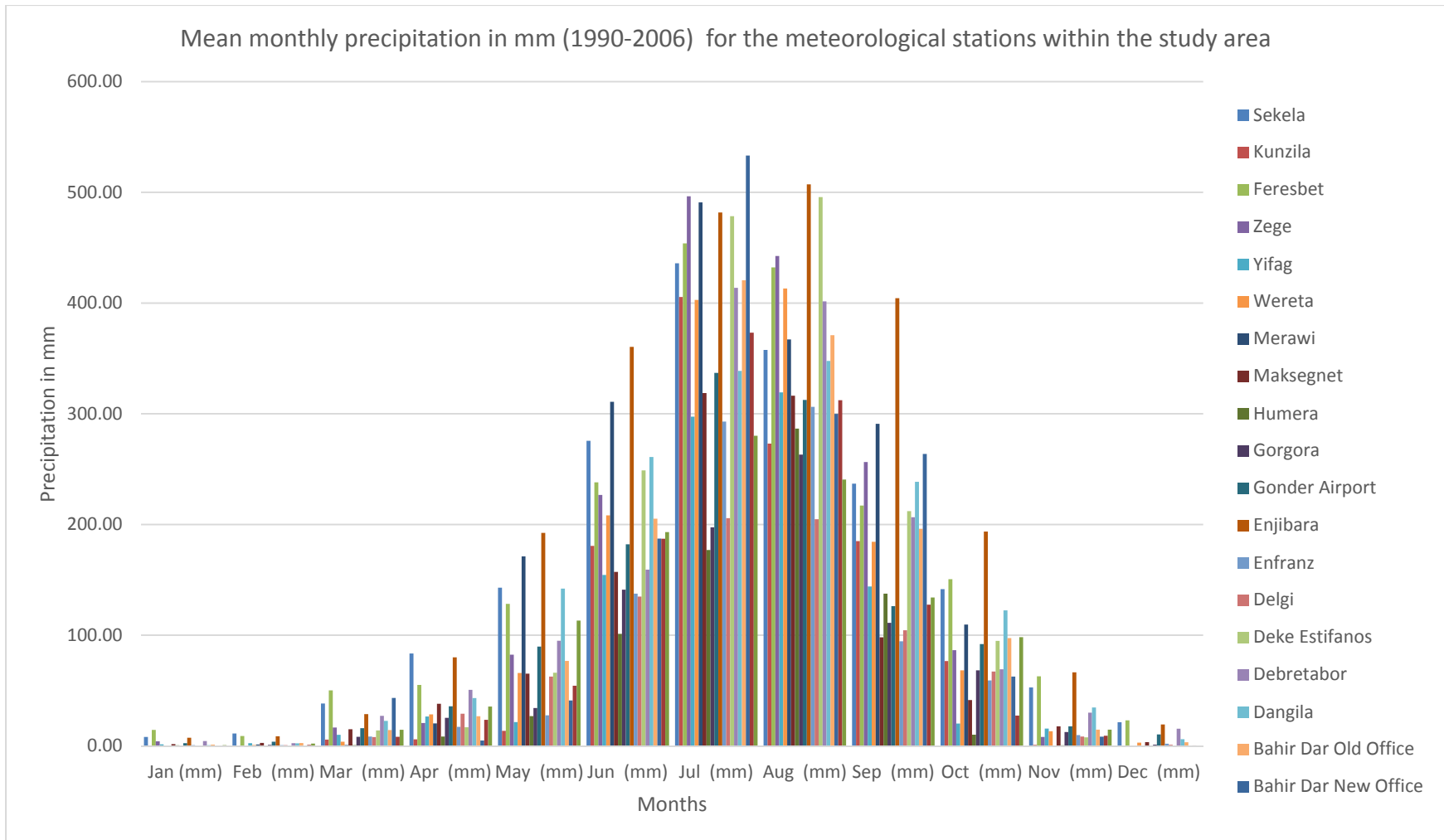


Figure 20: Mean monthly precipitation in mm for the different meteorological stations within the study area. The data covers the years from 1990-2006 and for each month the average per month for all the years is provided (Source: Samson Mengistu, 2010)

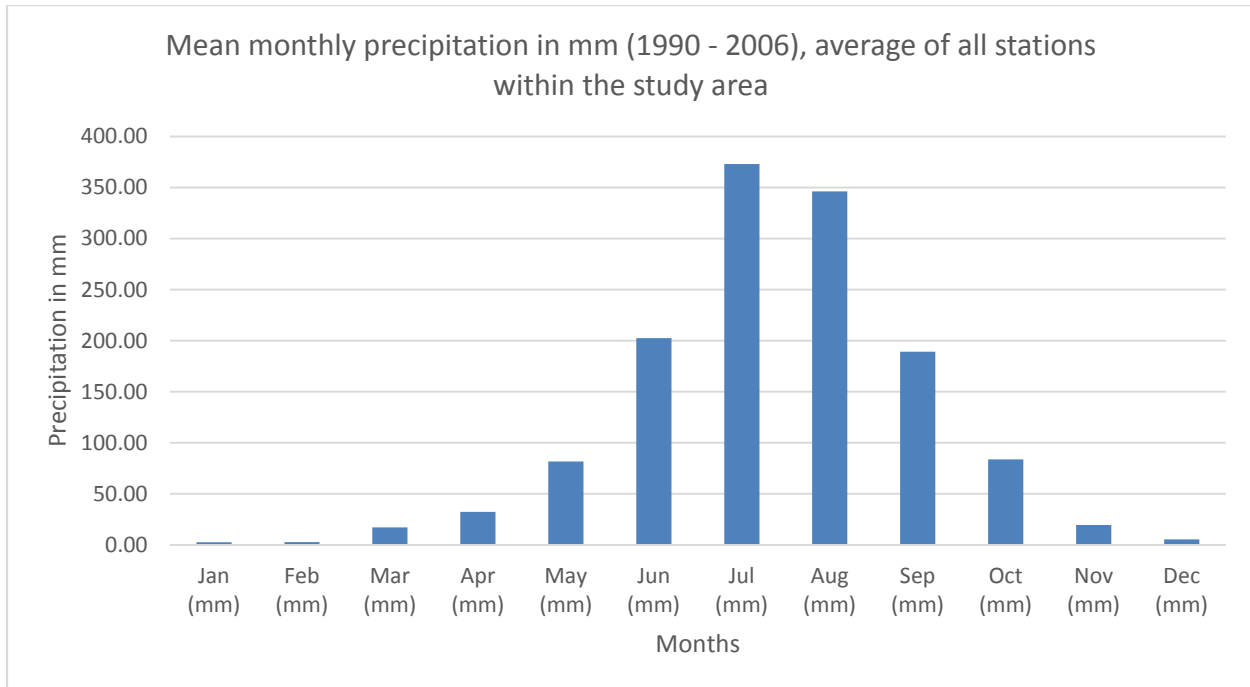


Figure 21: Mean monthly precipitation in mm for the study area (average of all stations). The data covers the years from 1990-2006 and for each month the average per month for all the years and stations has been calculated (Source: Samson Mengistu, 2010)

As far as concerning the erosivity of rainfall, the rainfall pattern of Lake Tana Sub Basin (LTSB) is presumed to be uni-modal, and commonly begins Mid-June and ends Mid-September (Fig. 21). Nonetheless, there is also unpredictable and short rainfall season which occurs between March and June. But for a couple of reason, this short rainfall season has little impact in terms of soil erosion by water. On one side even though the surface condition of the croplands is completely bare, as the time is long dry season, the soil water is completely exhausted and the infiltration rate is very high at the time when rainfall starts. For that reason, the period has relatively less erosion risk. On the other hand, since the rainfall period is very short and the precipitation amounts are not that high (see Figures 20 and 21), the rainfall amount is not sufficient for the soil to become fully saturated. For the reason mentioned above, the period between Mid-June and September is taken as erosion risk periods, as precipitation is high (see Figures 20 and 21). Following these justifications out of the 23 Moderate-Resolution Imaging Spectro-radiometer (MODIS) EVI band only 6 of them were selected (Mid June to last June, July first to Mid-July and Mid July to Last July and August first to Mid-August and Mid-August to Last August). These periods in MODIS EVI data are represented by 12-18 bands.

Afterwards, temporal EVI value for each pixels is examined and translated to an erosion risk rank (High - Low). The Rank is initially translated after cropland vegetation condition is assessed. The ranks are given randomly and High represents relatively the highest risk and Low is the least and in between ranks go according to their order of importance. Besides to that, intersecting the crop type map with the Erosion risk map, it was tried to link the land use practice, crop phenology and erosion risk. The results and interpretation of the findings are presented in brief below. In fact, to understand the actual erosion risk of LTSB, several criteria have to be considered. Major determinants of soil erosion can be related to geological formations and geomorphology, which affect the topography and soil types. In addition to factors related to geology, erosion process are also related to the rainfall pattern and vegetation dynamics over the year. In this study only the vegetation dynamics over time and space have been considered and related to erosion risk.

According to Hans Hurni (1983), four major contributing factors can be identified for soil erosion as a major form of land degradation: rainfall erosivity, soil erodibility, land slope and land use practices. Moreover, according to the EHRS (1986) report, in the highlands of Ethiopia, more than 80% of the soil loss is generated from croplands. Hence, locating and identifying this huge soil loss sources demands critical assessment of the cropland separately. Even though appropriate soil erosion assessment needs thorough analysis of all these factors together, often this huge soil loss source is not properly following the approaches mentioned by the present study. The long term research findings from Soil Conservation Research Project (SCRIP) revealed that harrowing croplands just following the first week after rainfall starts are more prone for erosion (Hans, 1987, 1989 and Hurni et.al., 2005). Keeping in mind all these research findings and recommendations, the present study depict a new means to understand and characterise surface vegetation condition of croplands. Using the approach briefly mentioned above, employing 2013 MODIS satellite data, the erosion risk maps were developed and presented in (Fig. 22).

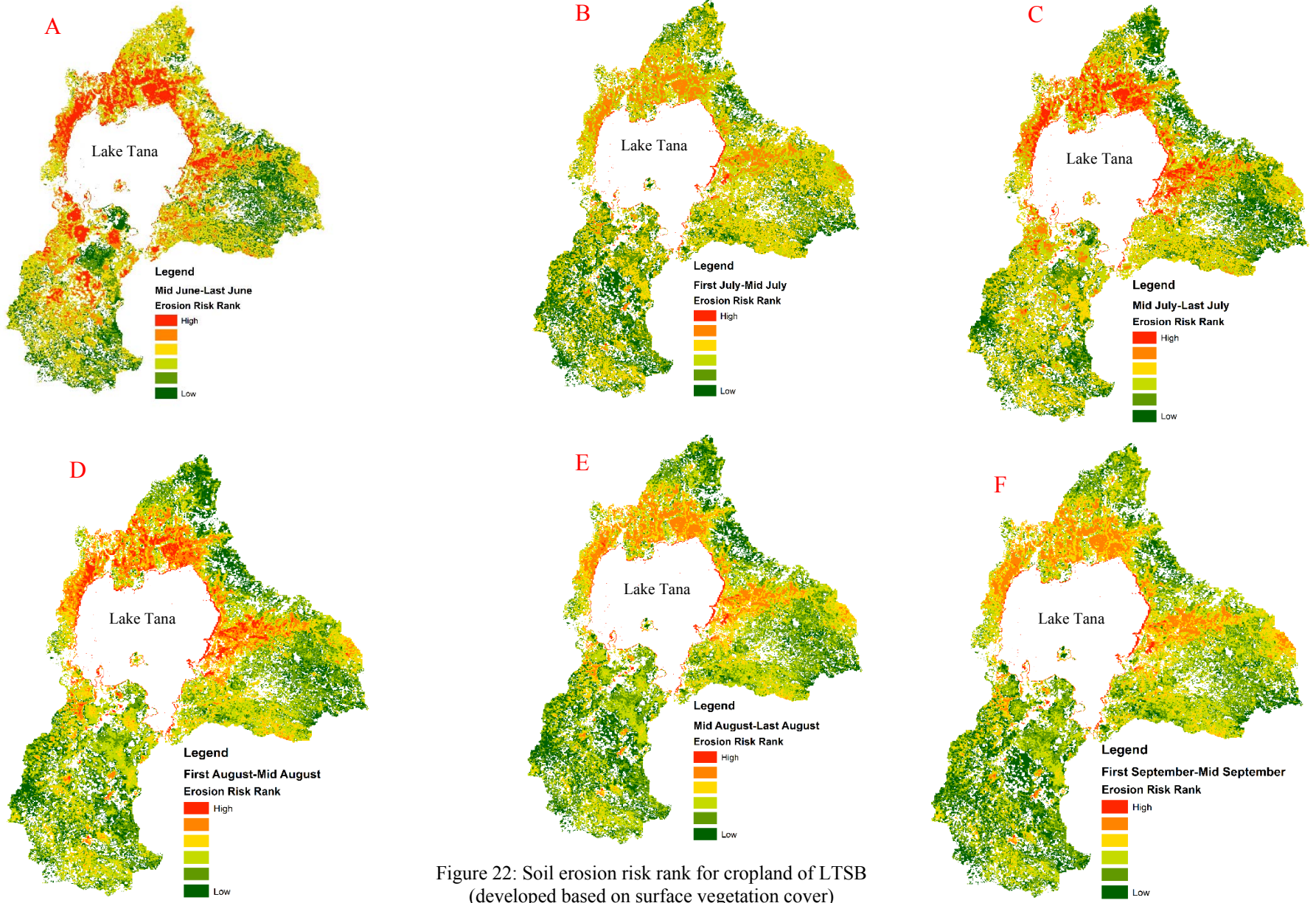


Figure 22: Soil erosion risk rank for cropland of LTSB (developed based on surface vegetation cover)

According to the maps presented above, red colour indicate high erosion risk while the green indicates low risk. However, attention has to be given that the analysis is based only on surface vegetation condition of croplands. In interpreting the results, other factors need to be considered like slope, land management and rainfall. In this regard, long-term rainfall data for LTSB region indicated that rainfall commonly starts just after mid of June. As a result, majority of the croplands are appeared bare since grass vegetation growth on croplands is not yet initiated.

However, ranking erosion risk only by its surface vegetation condition, it appeared that June mid to Jun last period is more severe than the other periods. But when we consider the erodibility of the soil since the soil is not yet saturated, we can find that this period has less erosion risk than the period between first July and mid-July. Moreover, the maps represent the actual situation only for the lowland particularly for the floodplain region. However, rainfall starts a bit earlier in the mid and highland part of the region as the area appeared greener, implying that, grass growth over crop landscapes is initiated before this period. For that reason, more erosion risk could be anticipated in the mid and highland regions than the floodplain for the fact that the floodplain has flat slope. The period between first July and mid-July has relatively better surface cover but more disturbance and more power of the rainfall makes the regions more vulnerable for soil erosion.

In addition to considering the rainfall and surface vegetation condition of croplands to rank erosion risk, overlaying the maps for different crop types growing in the region could help better to understand the erosion risk of croplands. In order to do that, crop type maps developed in section 4 can easily be overlaid and land use practices such as harrowing and sowing for each crop types could further lead to link and rank erosion risk. This kind of analysis in the present study is not made. However, from such analysis it would be possible even to quantify and assess soil erosion risk better.

CHAPTER FIVE

Conclusion and Recommendations

5.1. Conclusion

Mapping crop types and knowing their spatio-temporal variability is very useful for holistic ecosystem services and disservices assessment. However, the potential areal extent of major crops growing in Lake Tana Sub Basin (LTSB) has remained a major information gap for several development endeavours. Moreover, at country level it has remained a major research and development gap. In fact in the country, there exist official data compiled at Kebele level. However, the available data commonly collected by the government officials mainly the Agricultural offices has a couple of shortcomings. Firstly, it lacks credibility among all the data users including the government body due to quality problem. Secondly, the compilation of these information follows political administration while scientific and development oriented researches demand the same information at watershed level. To fill this important missing information mapping potential cropland as well as area extent of major crops at a watershed level has been appraised by the present study.

The overall accuracy of maps developed using the proposed methodology have been found promising to map croplands as well as to identify and map major crop types.

Nonetheless, the accuracy of the result has still some shortfalls. Among which, the crop type map developed by the present study is not very accurate. This is for the fact that several crop types growing in a particular region do have similar crop calendar and similar spectral property that spectral values of Enhanced Vegetation Index (EVI) couldn't differentiate. Moreover, double cropping nature, smaller dimension of the farm plots which couldn't be captured by the Moderate-Resolution Imaging Spectro-radiometer (MODIS) pixels, and seasonal variability of the crops growing in a particular region made the accuracy of the maps lower. With such complex challenges, the developed crop type maps using the proposed methodology are useful. Especially, if more criteria, more ground truth collected by intensive field visit, clear and detailed Traditional Cropping Calendar (TCC) are incorporated, the accuracy of the crop type maps would significantly improve.

Moreover, apart from mapping croplands and crop types, the usefulness of understanding and evaluating surface vegetation condition of croplands over time and space has been highlighted by the present study. The approach as well as the findings of the study underlined the usefulness of assessing cropland surface condition for comprehensive ecosystem services assessment.

In general, the researcher would like to expose the following experiences that others could encounter while they are employing the proposed methodology;

- Satellite image based mapping and assessment could be challenged by extremely varying climatic conditions which could prohibit to develop strong functional relationship between satellite data and cropping calendar.
- The theory and assumption that the present study took at the very beginning was crops have their own specific growing region mainly associated with altitude, rainfall and soil. However, since very recently improved varieties based farming has become very predominant in the region that prohibit the practicality of the hypothesis set at the beginning of the study.
- The comparison made between satellites based crop type mapping and their respective yield shows that satellite image based mapping significantly overestimate one crop and under estimate the other. This variation is more pronounced in some CGR and vary insignificantly over other areas. However, data disparity due to cultivated and non-cultivated land remained consistent across all administrative levels..

Generally, the present study concluded that dividing LTSB in to regions so that MODIS temporal data better related with the actual crop phenology has been found very practical approach in mapping complex and heterogeneous landscapes like LTSB. The proposed methodology could also allow to get spatially explicit information of cropland, crop types and production at pixel level.

5.2 Recommendations

Based on the findings of the present study, the following important recommendation have been drawn

- Assessment of ecosystem services demands accurate information of the croplands. However, unfortunately, extracting spatially explicitly information for such very dynamic earth features is very difficult exercises.
- The present study witnessed that this difficult exercise can be simplified if several geospatial data are integrated in the process. For complex landscapes like the highlands of Ethiopia, multi-criteria based classification algorithm perform better than the ready-made hard classification algorithms.
- Multi-temporal data have big potential to map seasonally dynamic landscapes like croplands than one-time multi-spectral and higher spatial resolution satellite data.
- If more criteria are integrated in the classification, better accuracy would be achieved and the potential of Multi-temporal MODIS data would be maximized.
- In this regard, decision tree based classification and information extraction has been found very useful to extract difficult information that one-time image couldn't provide.

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Annexes

Annex I Woreda Agricultural Office Crop type by Kebele (Sampe Woredas)

Table 1: Sekela woreda area, productivity and yield by crop type

W_NAME	W_CODE	RK_NAME	TA	TY	BA	BY	WA	WY	MA	MY	FBA	FBY	FPA	FPY	LUA	LUY	LSA	LSY	NA	NY
Sekela	30705	ABAY SANIGIB	88.50	12.00	295.00	30.00	357.00	28.00	78.95	38.00	76.00	16.00	60.80	15.00	38.55	22.00	16.20	5.00		
Sekela	30705	LICHIMA REBU GEBEYA	321.79	25.00	82.50	11.00	176.00	28.00	6.00	14.00	69.00	18.00	67.20	14.00	42.18	20.00	5.40	5.50		
Sekela	30705	Ambisi Wara	150.93	27.00	57.00	11.50	174.93	29.00			28.00	17.00	45.60	15.50	11.64	22.50	5.40	6.00		
Sekela	30705	KOLEL LECHA	265.93	27.50	109.50	10.00	165.33	31.00	24.00	13.00	27.00	15.00	33.60	15.50	26.91	22.50	12.60	6.00	11.67	7.00
Sekela	30705	Sewse	149.36	29.00	139.50	12.00	208.00	31.00	6.00	15.00	16.00	17.00	14.40	16.00	13.82	23.00	9.00	6.00		
Sekela	30705	Shurba Bifeta	78.93	14.50	472.50	12.50	183.47	30.50	364.00	14.50	33.00	16.50	12.80	15.50	33.45	22.50	9.00	5.50	55.00	6.50
Sekela	30705	GITIM TRARA	179.71	27.50	399.00	11.50	247.47	29.50	268.00	13.50	49.00	15.50	23.20	14.50	25.45	21.50	5.40	4.50	31.67	5.50
Sekela	30705	ABIYOT CHORA	153.00	30.00	141.00	14.00	192.00	32.00	12.00	16.00	42.00	18.00	30.40	17.00	24.00	24.00	5.40	7.00	15.00	8.00
Sekela	30705	Ginde Temem	66.00	12.00	185.79	28.00	145.07	29.00	4.00	13.00	36.00	16.00	20.80	14.00	16.00	22.00	3.60	5.00		
Sekela	30705	GUMOBILA	228.29	29.00	109.50	11.75	144.00	29.65			47.00	16.75	52.80	15.45	32.73	22.45	7.20	5.50	8.33	6.75
Sekela	30705	Solisela Derishe	183.36	28.00	79.50	12.00	167.47	31.00			34.00	16.00	34.40	15.00	9.45	23.00	3.60	5.00		
Sekela	30705	ABEKERES	172.43	28.50	82.50	12.50	164.27	28.50			63.00	15.75	32.80	15.50	17.45	22.75	9.00	6.00		
Sekela	30705	Abesken Gideta	162.71	27.00	97.50	13.00	133.33	29.00			43.00	15.00	44.00	16.00	18.91	23.00	7.20	5.00		
Sekela	30705	GULESHA LEGNA	229.86	29.00	136.50	11.50	210.13	31.00			96.00	17.00	42.40	16.00	8.00	21.00	12.60	6.00	3.33	6.50
Sekela	30705	LIJAMIBERATETA	241.64	29.00	205.50	13.00	137.60	31.00			77.00	17.00	79.20	16.00	9.45	23.00	21.60	6.00	11.67	6.50

Dengila	3090 1	Abadra Agaga	760.0 0	18.00	695.00	32.00			116.00	40.50	205.00	12.00	275.00	14.00					96	8
Dengila	3090 1	Wendafay Mikael	359.1 3	18.00	948.13	36.00	2.50	18.00	659.00	38.00	202.50	28.00	262.00	20.00			6.00	7.00	12.00	10.00
Dengila	3090 1	Mangud T/Heymanot	252.0 0	12.78	2215.50	20.00			290.50	49.30	84.00	4.00	74.00	4.00			3.50	3.50	2.50	4.00
Dengila	3090 1	Wufatadate	637.0 0	18.00	25.00	21.00			642.00	41.00			18.00	12.00	31.00	20.00			65.75	15.00
Dengila	3090 1	Afesa	335.0 0	7.00	25.00	5.00			389.07	20.00					74	8	4	5	78.00	6.00
Dengila	3090 1	Wumbri Wurafta	255.0 0	10.00	0.61	8.00			391.00	38.00					15	6			100.00	4.50
Dengila	3090 1	Muksi	402.0 0	9.00	460.50	14.00			413.00	25.00									210.00	6.00
Dengila	3090 1	Ligaba	139.0 0	8.00	413.00	10.00			419.00	20.00					18	18			78.00	4.00
Dengila	3090 1	Zguda Gult	128.0 0	8.00	341.00	10.00			320.00	21.00			64	4.5	15	16			96.00	8.00
Dengila	3090 1	Zguda Gult	280.0 0	8.00	8.00	6.00			454.00	40.00									43.00	2.50
Dengila	3090 1	Washana Kuablta	271.7 5	14.00	393.00	18.00	24.75	10.00	265.00	44.00	113.00	8.00	119.00	8.00	6.25	10.00			3.75	8.00
Dengila	3090 1	Bachademsa	285.0 0	15.00	225.00	16.00	3.00	9.00	280.00	34.00	6.00	8.00	64.00	8.00	15.00	12.00	1.00	6.00	10.00	5.00
Dengila	3090 1	Zelisa Simalta	194.0 0	13.00	10.50	16.00			224.00	38.00			21.00	8.00					21.00	4.00
Dengila	3090 1	Gumbri Abela Akana	637.0 0	8.00	25.00	10.00			642.00	34.00			18.00	8.00			0.75	8	65.75	4.00
Dengila	3090 1	Gayta	299.0 0	20.00	20.00	32.00			265.00	41.00			1.00	4.00	1.00	13.00	2.00	6.00	120.00	10.00
Dengila	3090 1	Zubura Kuandsha	158.0 0	10.00	15.00	12.00			189.00	15.00	3.00	7.00	19.80	6.00	5.00	6.00			5.50	4.00

Table 2: Dangla woreda area, productivity and yield by crop type

Table 3: Fagita woreda area, productivity and yield by crop type

Fagita Lekom a	30905	FARI JEGOLA	308.00	14.00	70.00	16.00	84.00	18.00	43.00	18.00	3.00	12.50	8.00	12.00	35.00	16.00	2.00	9.00	62.00	13.00	71.00	13.00
Fagita Lekom a	30905	SEGILA T\HAYIMANO T	298.00	18.00	70.00	14.00	30.00	15.00	203.00	50.00					16.00	13.00			120.00	13.00	81.00	20.00
Fagita Lekom a	30905	SEGILA K\MIHIRET	295.00	17.00	63.00	13.00			313.00	54.00					28.00	13.00			130.00	11.00	285.00	22.00
Fagita Lekom a	30905	WAZINA AKABABIW	520.00	24.00					834.00	65.00					15.00	13.00			330.00	13.50	385.00	28.00
Fagita Lekom a	30905	DIMAMA MANIGUDA	201.00	24.00					560.00	65.00					26.00	12.00			190.00	11.50	320.00	25.00
Fagita Lekom a	30905	SEGILA DAWENA	420.00	14.00	106.00	18.00	120.00	20.00			7.00	12.50	9.00	12.00	105.00	18.00	3.00	8.00	140.00	12.50	84.00	15.00
Fagita Lekom a	30905	AZIMACH GOLA	405.00	12.00	75.00	18.00	65.00	6.00			4.00	12.50	5.00	12.00	25.00	20.00			41.00	12.00	48.00	14.00
Fagita Lekom a	30905	GAFERA	306.00	11.00	97.00	18.00	163.00	25.00			14.00	12.50	17.00	10.00	18.00	16.00			31.00	11.00		
Fagita Lekom a	30905	ZEMIBELA	302.00	14.00	65.00	25.00	24.00	18.00	20.00	24.00	11.00	13.00	24.00	12.00	3.00	16.00			35.00	12.00		
Fagita Lekom a	30905	AMESHA SHENIKORI	85.00	11.00	25.00	20.00	23.00	18.00			2.00	12.50	5.00	12.00	13.00	16.00			11.00	10.00		
Fagita Lekom a	30905	ENIDEWIHA ARETS	300.00	11.00	155.00	18.00	150.00	20.00	30.00	13.00	18.00	12.00	22.00	12.50	38.00	16.00			30.00	8.00		
Fagita Lekom a	30905	AMBAW MARIYAM	200.00	18.00	30.00	12.00			455.00	60.00					65.00	12.00			95.00	13.00	350.00	24.00
Fagita Lekom a	30905	Ashewa Afri	560.00	18.00	80.00	14.00	15.00	15.00	430.00	60.00					39.00	15.00			80.00	13.00	101.00	20.00
Fagita Lekom a	30905	Tamech Dambul	512.00	18.00	41.00	14.00	10.00	15.00	450.00	60.00					68.00	13.00			85.00	14.00	228.00	20.00

Annex II Traditional Cropping Calendar

The following graphs represent TCC plotted by crop phenology (in the y axis) and weeks of the year(x axis)

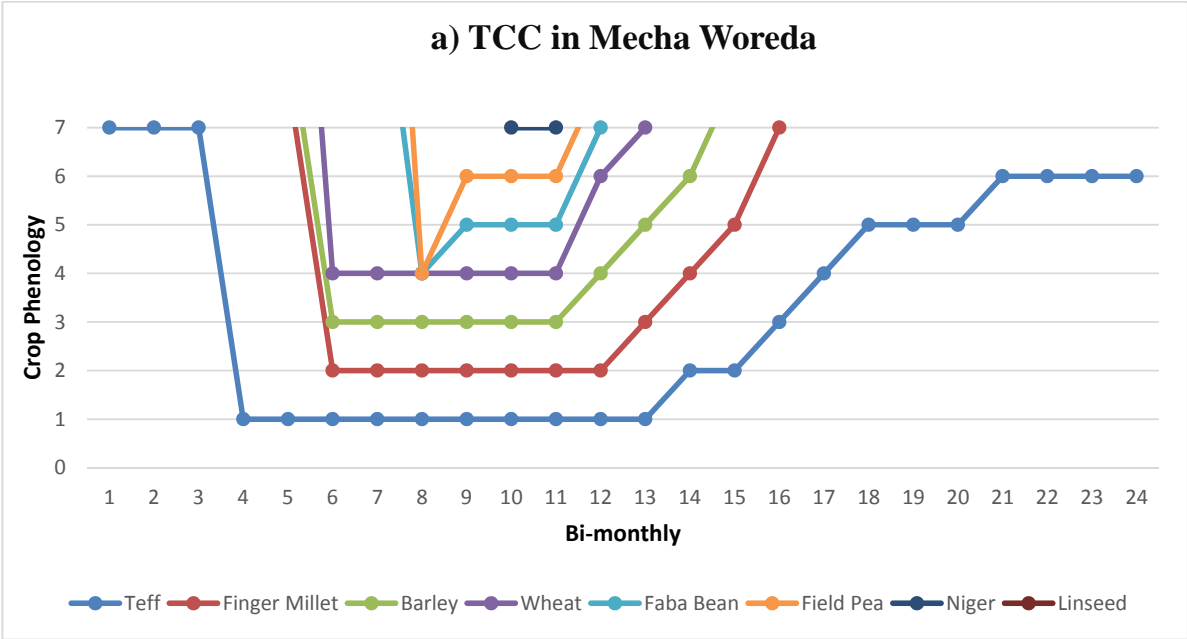


Figure 1: Traditional Cropping Calendar for Mecha Woreda

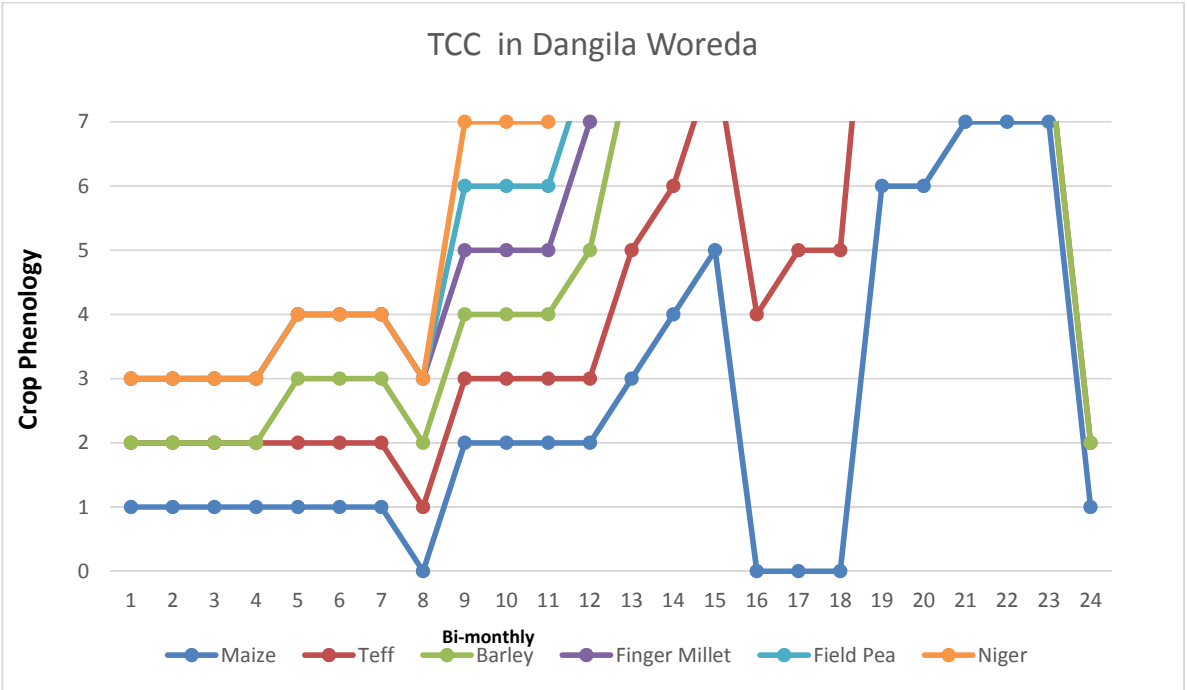


Figure 2: Traditional Cropping Calendar for Dangila Woreda

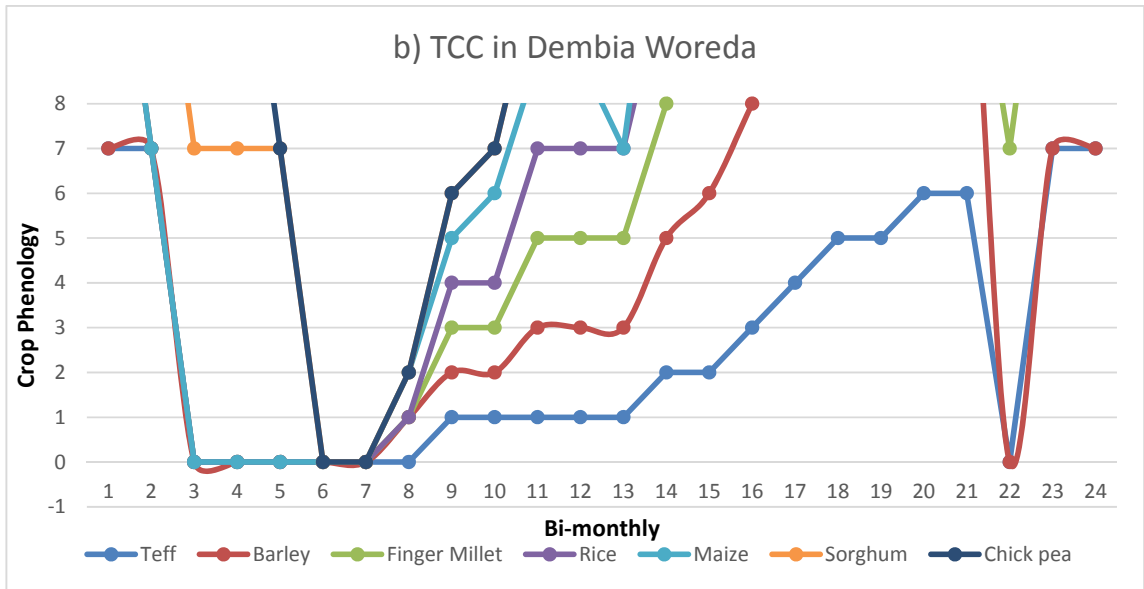


Figure 3: Traditional Cropping Calendar for Dembia Woreda

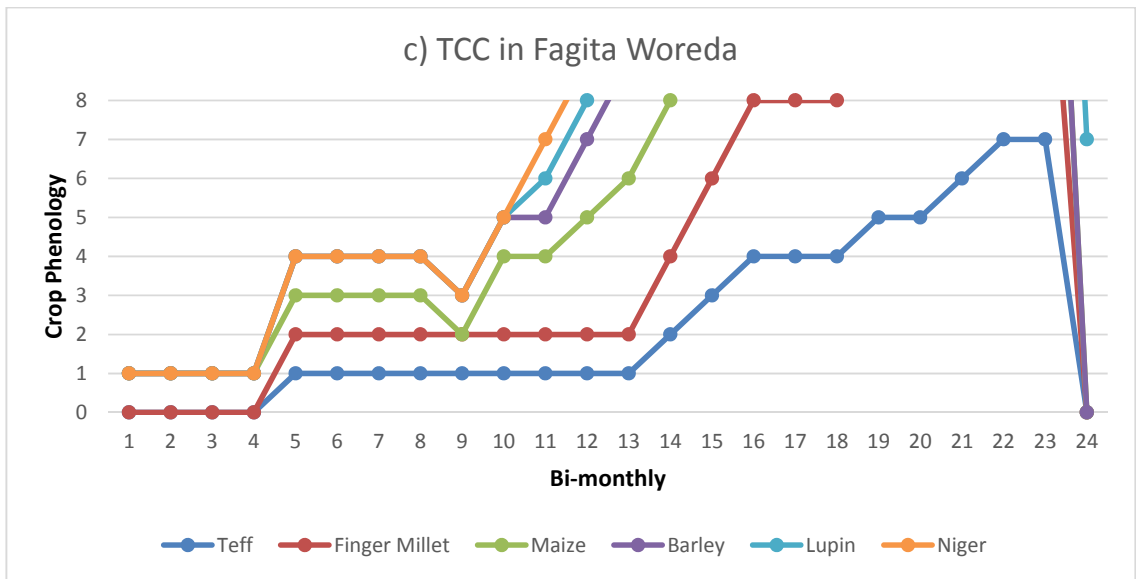


Figure 4: Traditional Cropping Calendar for Fagita Woreda

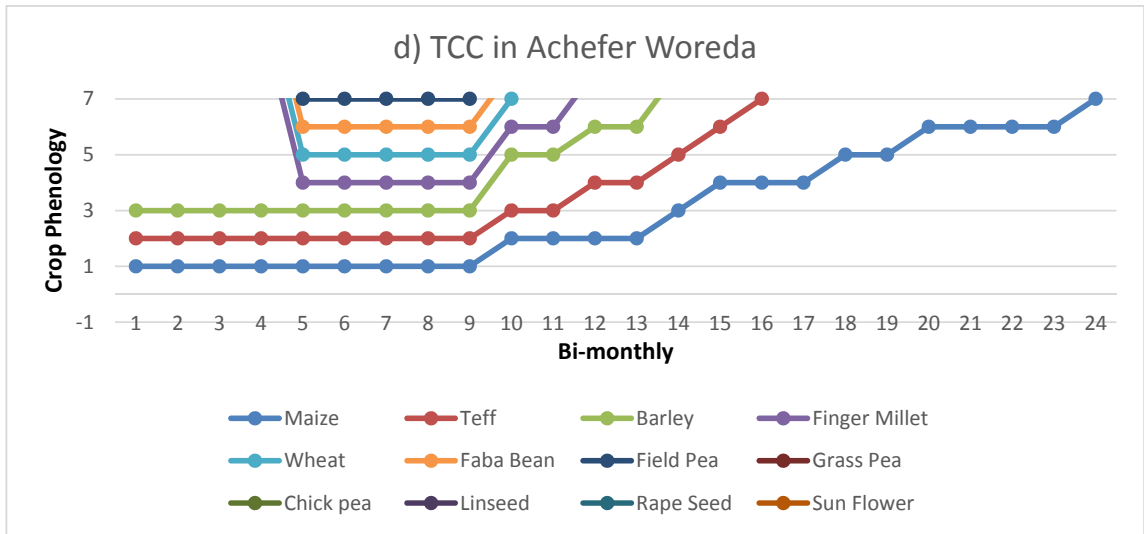


Figure 5: Traditional Cropping Calendar for Achefer Woreda

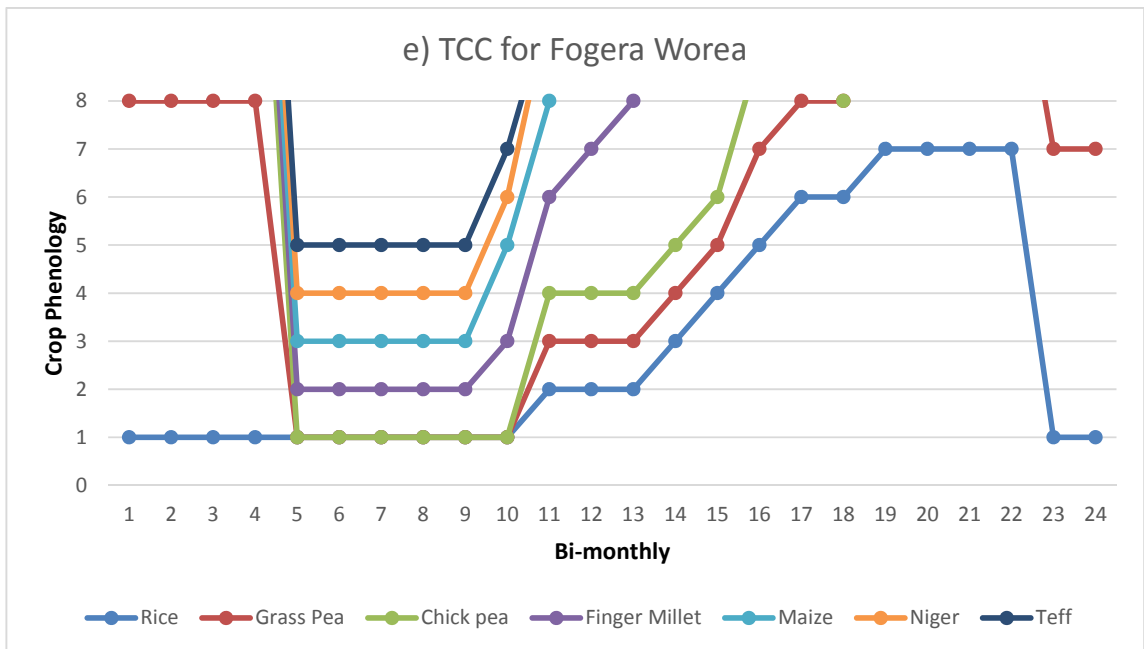


Figure 6: Traditional Cropping Calendar for Fogera Woreda

Annex III Decision Tree (DT) Classification

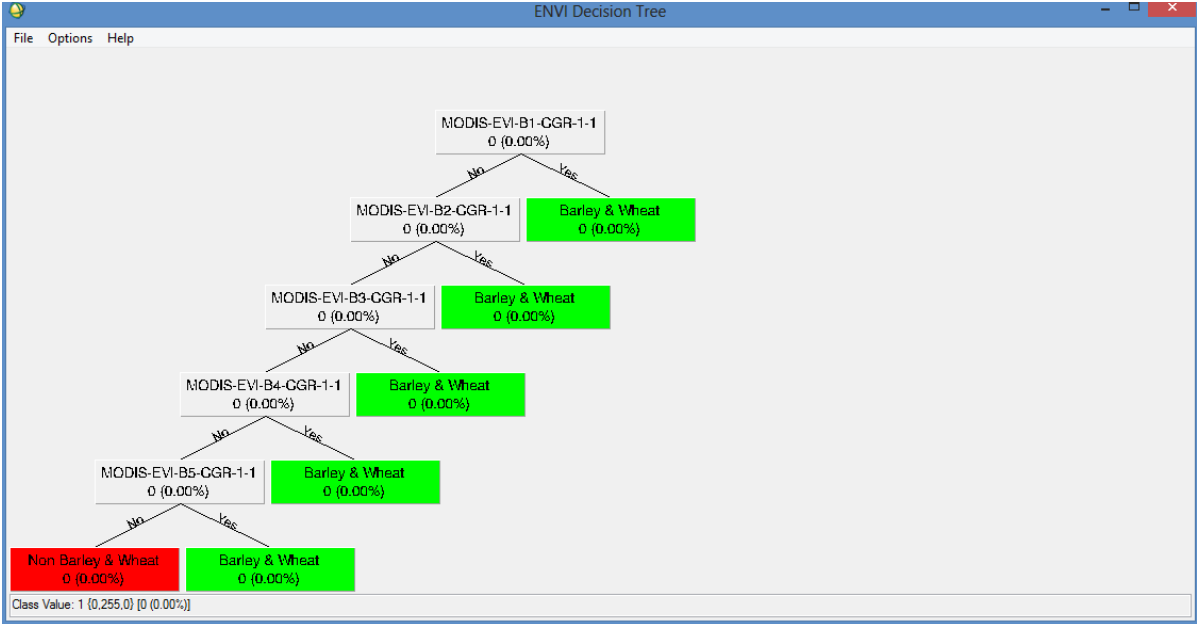


Figure 7: DT and involved criteria and rules to classify crop types (Wheat and Barely)

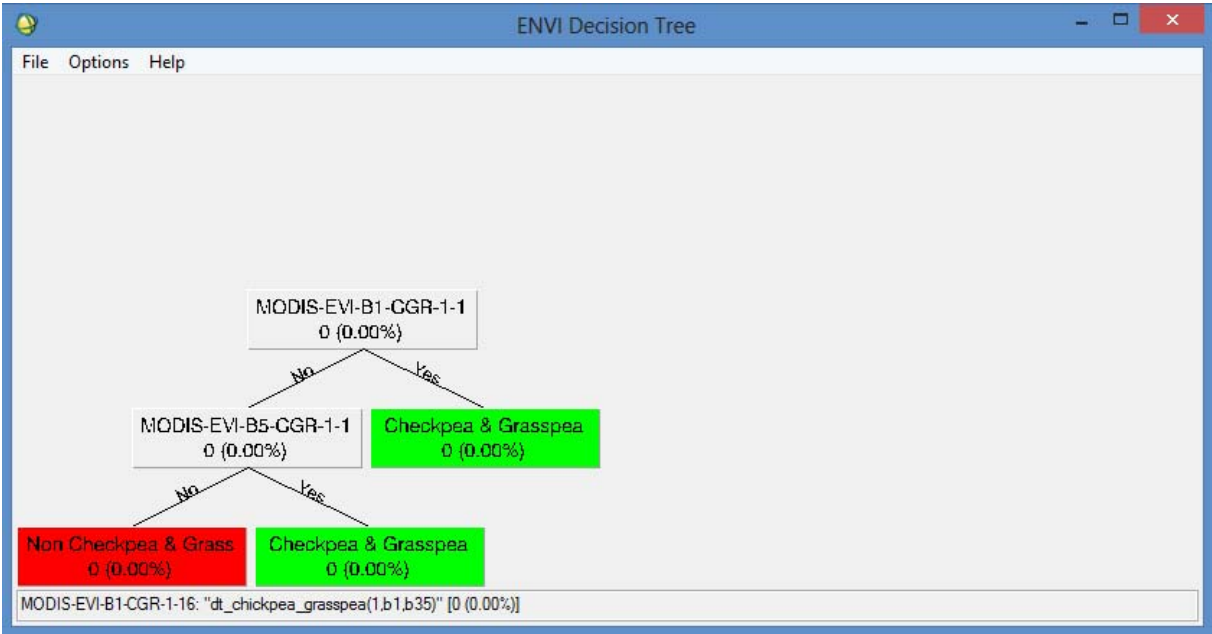


Figure 8: DT and involved criteria and rules to classify crop types (Chickpea and Grass pea)

Annex IV Interactive Data Language (IDL) functions

```

IDL - C:\Program Files (x86)\ENVI50\classic\save_add\dt_cropland_initial.pro - IDL
File Edit Source Project Run Window Help
Open New File New Project Save Cut Copy Paste Undo Back Forward Compile Run Stop In Over Out SMAINS Call Stack Reset
dt_cropland_initial.pro dt_cropland_initial.pro dt_cropland_initial.pro dt_cropland_initial.pro dt_barley.pro dt_chickpea.pro dt_teff_fingermil...
FUNCTION dt_cropland_initial,dt,data,aer
info = SIZE(data)
result = MAKE_ARRAY(/BYTE, SIZE = info)
CASE dt OF
1: BEGIN
result += ((data GE 805 AND data LE 4313 AND aer EQ 1) OR (data GE 940 AND data LE 4768 AND aer EQ 2) $
OR (data GE 462 AND data LE 4022 AND aer EQ 3) OR (data GE 598 AND data LE 4260 AND aer EQ 4) OR $
(data GE 1021 AND data LE 4633 AND aer EQ 5) OR (data GE 455 AND data LE 3849 AND aer EQ 6) OR $
(data GE -151 AND data LE 5524 AND aer EQ 7) OR (data GE 772 AND data LE 3862 AND aer EQ 8) OR $
(data GE -12 AND data LE 5100 AND aer EQ 9) OR (data GE -12 AND data LE 4878 AND aer EQ 10) OR $
(data GE 840 AND data LE 3199 AND aer EQ 11) OR (data GE 780 AND data LE 2937 AND aer EQ 12) OR $
(data GE 176 AND data LE 4869 AND aer EQ 13) OR (data GE 628 AND data LE 3723 AND aer EQ 14))
END
2: BEGIN
result += ((data GE 673 AND data LE 4147 AND aer EQ 1) OR (data GE 769 AND data LE 4980 AND aer EQ 2) $
OR (data GE 642 AND data LE 4301 AND aer EQ 3) OR (data GE 802 AND data LE 3665 AND aer EQ 4) OR $
(data GE 1261 AND data LE 4522 AND aer EQ 5) OR (data GE 712 AND data LE 4618 AND aer EQ 6) OR $
(data GE 53 AND data LE 5794 AND aer EQ 7) OR (data GE 546 AND data LE 3375 AND aer EQ 8) OR $
(data GE -197 AND data LE 4896 AND aer EQ 9) OR (data GE 134 AND data LE 4576 AND aer EQ 10) OR $
(data GE 609 AND data LE 4286 AND aer EQ 11) OR (data GE 685 AND data LE 3854 AND aer EQ 12) OR $
(data GE 728 AND data LE 5026 AND aer EQ 13) OR (data GE 656 AND data LE 3881 AND aer EQ 14))
END
3: BEGIN

```

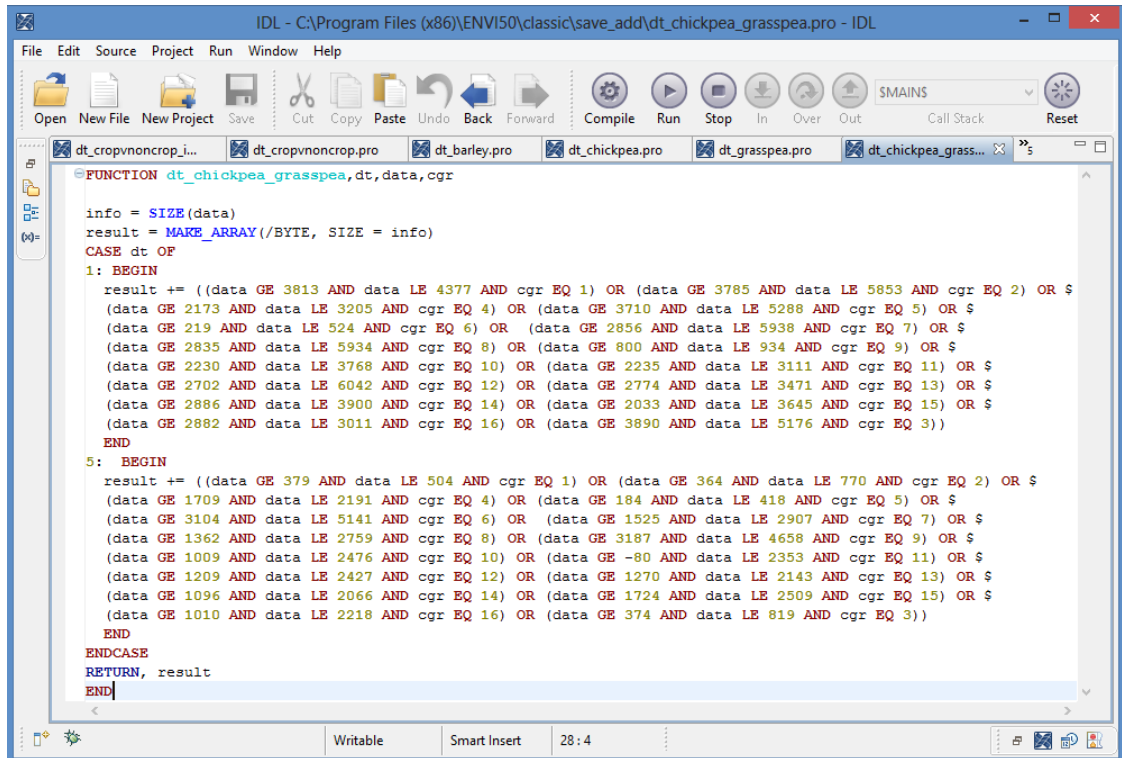
Figure 9: IDL functions and syntaxes to classify cropland and non-cropland

```

IDL - C:\Program Files (x86)\ENVI50\classic\save_add\dt_barley.pro - IDL
File Edit Source Project Run Window Help
Open New File New Project Save Cut Copy Paste Undo Back Forward Compile Run Stop In Over Out SMAINS Call Stack Reset
dt_cropland_initial.pro dt_cropland_initial.pro dt_barley.pro dt_chickpea.pro dt_grasspea.pro dt_chickpea_grass...
FUNCTION dt_barley,dt,data,cgr
info = SIZE(data)
result = MAKE_ARRAY(/BYTE, SIZE = info)
CASE dt OF
1: BEGIN
result += ((data GE 813 AND data LE 4377 AND cgr EQ 1) OR (data GE 785 AND data LE 853 AND cgr EQ 2) OR $
(data GE 890 AND data LE 976 AND cgr EQ 3) OR (data GE 710 AND data LE 888 AND cgr EQ 5) OR $
(data GE 835 AND data LE 934 AND cgr EQ 8) OR (data GE 800 AND data LE 934 AND cgr EQ 9) OR $
(data GE 230 AND data LE 768 AND cgr EQ 10) OR (data GE 886 AND data LE 900 AND cgr EQ 14) OR $
(data GE 133 AND data LE 645 AND cgr EQ 15) OR (data GE 882 AND data LE 1011 AND cgr EQ 16) OR $
(data GE 774 AND data LE 971 AND cgr EQ 13))
END
2: BEGIN
result += ((data GE 126 AND data LE 295 AND cgr EQ 1) OR (data GE 166 AND data LE 665 AND cgr EQ 2) OR $
(data GE 785 AND data LE 810 AND cgr EQ 3) OR (data GE 281 AND data LE 670 AND cgr EQ 5) OR $
(data GE 838 AND data LE 942 AND cgr EQ 8) OR (data GE 572 AND data LE 889 AND cgr EQ 9) OR $
(data GE 100 AND data LE 105 AND cgr EQ 10) OR (data GE 656 AND data LE 895 AND cgr EQ 14) OR $
(data GE 966 AND data LE 1717 AND cgr EQ 15) OR (data GE 886 AND data LE 960 AND cgr EQ 16) OR $
(data GE 500 AND data LE 690 AND cgr EQ 13))
END
3: BEGIN

```

Figure 10: IDL functions and syntaxes to classify crop types (Barley and Wheat)



```
IDL - C:\Program Files (x86)\ENVI50\classic\save_add\dt_chickpea_grasspea.pro - IDL
File Edit Source Project Run Window Help
Open New File New Project Save Cut Copy Paste Undo Back Forward Compile Run Stop In Over Out SMAINS Call Stack Reset
dt_croprvnoncrop_i... dt_croprvnoncrop.pro dt_barley.pro dt_chickpea.pro dt_grasspea.pro dt_chickpea_grass...
FUNCTION dt_chickpea_grasspea, dt, data, cgr
info = SIZE(data)
result = MAKE_ARRAY(/BYTE, SIZE = info)
CASE dt OF
1: BEGIN
result += ((data GE 3813 AND data LE 4377 AND cgr EQ 1) OR (data GE 3785 AND data LE 5853 AND cgr EQ 2) OR $
(data GE 2173 AND data LE 3205 AND cgr EQ 4) OR (data GE 3710 AND data LE 5288 AND cgr EQ 5) OR $
(data GE 219 AND data LE 524 AND cgr EQ 6) OR (data GE 2856 AND data LE 5938 AND cgr EQ 7) OR $
(data GE 2835 AND data LE 5934 AND cgr EQ 8) OR (data GE 800 AND data LE 934 AND cgr EQ 9) OR $
(data GE 2230 AND data LE 3768 AND cgr EQ 10) OR (data GE 2235 AND data LE 3111 AND cgr EQ 11) OR $
(data GE 2702 AND data LE 6042 AND cgr EQ 12) OR (data GE 2774 AND data LE 3471 AND cgr EQ 13) OR $
(data GE 2886 AND data LE 3900 AND cgr EQ 14) OR (data GE 2033 AND data LE 3645 AND cgr EQ 15) OR $
(data GE 2882 AND data LE 3011 AND cgr EQ 16) OR (data GE 3890 AND data LE 5176 AND cgr EQ 3))
END
5: BEGIN
result += ((data GE 379 AND data LE 504 AND cgr EQ 1) OR (data GE 364 AND data LE 770 AND cgr EQ 2) OR $
(data GE 1709 AND data LE 2191 AND cgr EQ 4) OR (data GE 184 AND data LE 418 AND cgr EQ 5) OR $
(data GE 3104 AND data LE 5141 AND cgr EQ 6) OR (data GE 1525 AND data LE 2907 AND cgr EQ 7) OR $
(data GE 1362 AND data LE 2759 AND cgr EQ 8) OR (data GE 3187 AND data LE 4658 AND cgr EQ 9) OR $
(data GE 1009 AND data LE 2476 AND cgr EQ 10) OR (data GE -80 AND data LE 2353 AND cgr EQ 11) OR $
(data GE 1209 AND data LE 2427 AND cgr EQ 12) OR (data GE 1270 AND data LE 2143 AND cgr EQ 13) OR $
(data GE 1096 AND data LE 2066 AND cgr EQ 14) OR (data GE 1724 AND data LE 2509 AND cgr EQ 15) OR $
(data GE 1010 AND data LE 2218 AND cgr EQ 16) OR (data GE 374 AND data LE 819 AND cgr EQ 3))
END
ENDCASE
RETURN, result
END
```

Figure 11: IDL functions and syntaxes to classify crop types (For chickpea and Grass pea)

Annex V Mean Monthly Precipitation (1990-2006)

Gauge Station	Jan (mm)	Feb (mm)	Mar (mm)	Apr (mm)	May (mm)	Jun (mm)	Jul (mm)	Aug (mm)	Sep (mm)	Oct (mm)	Nov (mm)	Dec (mm)	Total per year
Sekela	8.11	11.29	38.31	83.54	142.95	275.53	435.87	357.62	236.93	141.58	52.82	21.42	1,805.97
Kunzila	0.50	0.00	5.80	6.00	13.60	180.70	405.50	273.10	185.00	76.70	1.00	0.00	1,147.90
Feresbet	14.51	9.03	50.25	55.10	128.31	238.06	453.93	432.23	217.14	150.64	62.84	23.15	1,835.19
Zege	4.16	0.13	16.65	20.69	82.49	226.67	496.37	442.53	256.44	86.48	8.14	0.36	1,641.11
Yifag	1.45	2.50	10.05	26.55	21.60	154.40	297.35	319.35	144.00	20.30	15.65	0.00	1,013.20
Wereta	0.10	0.86	3.88	28.52	65.93	208.29	402.85	413.16	184.34	68.26	13.29	2.99	1,392.47
Merawi	0.40	1.35	0.80	20.40	171.25	310.80	490.90	367.10	290.95	109.60	0.00	0.00	1,763.55
Maksegnat	1.73	2.74	15.13	38.05	65.33	157.18	318.67	316.29	98.17	41.50	17.78	3.47	1,076.04
Humera	0.63	0.00	0.77	8.53	26.93	101.25	176.92	286.60	137.50	10.15	0.58	0.00	749.86
Gorgora	0.00	1.00	8.30	25.35	34.23	141.13	197.40	263.13	111.20	68.30	12.63	1.25	863.92
Gonder Airport	2.47	3.80	16.01	35.81	89.76	182.09	336.93	312.52	126.33	91.98	17.71	10.42	1,225.83
Enjibara	7.45	8.74	28.81	80.02	192.48	360.44	481.79	507.17	404.45	193.60	66.54	19.41	2,350.90
Enfranz	0.70	0.75	8.48	17.30	27.62	137.50	292.95	306.28	94.52	59.15	9.79	1.98	957.02
Delgi	0.39	0.75	8.03	29.16	62.67	134.86	205.71	204.74	104.44	67.23	8.46	1.08	827.52
Deke Estifanos	0.35	0.35	14.05	16.83	66.19	248.91	478.41	495.65	212.08	94.92	7.82	0.00	1,635.56
Debretabor	4.38	2.52	27.25	50.73	95.04	159.27	413.74	401.51	206.61	69.26	30.11	15.53	1,475.95
Dangila	0.73	2.33	22.65	43.22	142.11	260.95	338.72	347.74	238.58	122.43	34.73	6.13	1,560.32
Bahir Dar Old Office	1.20	2.57	14.41	26.89	76.84	205.24	420.60	370.95	196.10	97.38	14.71	3.38	1,430.27
Bahir Dar New Office	0.35	0.05	43.40	4.95	41.10	187.30	533.20	299.85	263.70	62.70	8.35	0.00	1,444.95
Addiszemen Police	0.00	0.99	8.32	23.55	54.36	187.16	373.23	312.27	127.61	27.41	9.18	0.53	1,124.61
Aykel	0.72	2.14	14.65	35.60	113.28	193.20	280.16	240.63	134.04	98.21	14.76	0.38	1,127.77
Basin Average	2.40	2.57	16.95	32.23	81.62	202.43	372.91	346.21	189.05	83.70	19.38	5.31	1,354.76

Source: Samson Mengistu 2010

