Wisdom at the source of the Blue Nile

Volume 4: Number 2
Oct, 2019

Journal of Agriculture and Environmental Sciences (JAES)

Publication of the College of Agriculture and Environmental Sciences
Bahir Dar University, Ethiopia
http://www.bdu.edu.et/caes
ISSN: 2616-3721 (Online); 2616-3713 (Print)

Progress, Challenges and Implications of Land Use/Land Cover Detection Methods in Ethiopia: A Review

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Received: February 30, 2019 Accepted: May 1, 2019

Abstract: *Remote sensed imageries are rich in geospatial data's pertinent for natural resources conservation. However, extracting accurate and reliable information was remained critical. This review is aimed to compile the progress, challenges and examine implications of land use/land cover detection methods executed in Ethiopia. In the diverse landscape of Ethiopia, existing satellite image classification techniques were operated. Most of the studies agreed that automatic techniques are crucial in detecting the spectral responses of features. However, it was limited under heterogeneous landscape. To retain its digital recognition, a successive hybrid of the automatic techniques were also executed then again doubted by its limitation on areas which have similar reflectance for different land covers. Other studies also applied on-screen-digitizing, which bears better accuracy but criticized as it was exhaustive, costly, and expert dependent on fine-resolution data. In order to reduce the limitations and incorporate their advantages, a hybrid of automatic and on-screen-digitizing has been effected. Even though this technique refined spectral confusion sourced from automatic operation with better accuracy, the drawback of on-screen-digitizing was followed. Indeed, if an error happen in data processing, it is obvious that decisions and modeling outputs could be doubtful. In so far, those studies showed virtuous progress in adopting the tools to Ethiopia. Nevertheless, the absence of well-organized, accessible, and up-to-date information catalog, the country was investing (in/directly) for those fragmented studies. Devising site-specific methodologies, providing accurate inputs for modeling and decision makers, organizing fragmented studies, and establishment of an accessible resource assessment database are recommended.*

Keywords: GIS, Hybrid Classification, land use/land cover, on-screen-digitizing, Remote Sensing, Supervised Classification

1. Introduction

All human kinds were directly or indirectly involved in the adaptation of landscape to fulfill the livelihood demands. This intrusion has transformed and disturbed the equilibrium condition of nature (Burka, 2008). The reason is that the land is the major natural resource that economic, social, infrastructure and other human activities are undertaken on (Fisseha *et al*., 2011). In order to convince decision makers and manage the extreme resource use, the global science agenda on environmental change becomes targeted in monitoring and providing information on unremittingly occurring land use/land cover change (LU/LCC) (Lambin *et al.*, 2001). As a tool to detect LU/LCC, ever since the launch of the first Land sat satellite (1972) and the old aged airborne platform products have been processed through remote sensing and geographic information system (GIS) to map the spatial characteristics of a landscape and its link among people (Giri, 2012).

Even though remote sensed imageries are rich in geographic data, the conversion of this raw data into meaningful form needs simple to complex geospatial processing (Balamurugan and Jayarraman, 2016). As it is compiled by Weng (2010), information extraction from those images needs the integration of remote sensing and GIS using (i) remote sensing as a tool for gathering data for use in GIS, (ii) GIS data as ancillary information to improve the products derived from remote sensing, and (iii) remote sensing and GIS together for modeling and analysis.

In either of using the semi/self-executing (automatic), manual or combination of them (hybrid) techniques of image classification, the information should be accurate and acceptable in line with existing landscape conditions (Meshesha *et al*., 2014; Abburu and Golla, 2015). Zhang *et al*. (2014) indicated that automated methods could provide satisfactory results when applied to homogeneous land covers like water bodies, built-ups, and sandy land. Similarly, recent studies reported inefficiency of this approach in extracting LU/LC information from heterogeneous landscape (Büttner, 2014; Meshesha *et al*., 2014; Wondrade *et al.,* 2014; Sahle *et al*., 2016; Mekonnen *et al*., 2016; Betru *et al*., 2019). Those authors recommended the use of either hybrid or manual approaches. The rationale is that the application of automatic classification is more limited in a larger area because of the massive parameter requirement to handle spectral confusion (Herold *et al.,* 2008). This is an implication that automated image classification should be classified based on some considerations (Herold *et al.,* 2008).

Spatial heterogeneity emanated from soil type, topography, farming practices and land use history makes the estimation of global degraded lands vary across larger spatial scales (Gibbs and Salmon, 2015). The African continental-scale land cover mapping through fuzzy (crisp) approach is employed on four different datasets. The result revealed that mapping of heterogeneous landscapes in the four products is not very successful. In the end, using smarter algorithms, better timing of image acquisition, and improved class definitions are options provided to overcome the challenge (Tchuenté *et al.,* 2011).

Ethiopia is characterized by enormous agro-ecosystems, which explained into diverse vegetation zones (Teketay *et al*., 2010). Despite great geographic diversity, there are areas where a growing population in conjunction with rising subsistence demand has contributed to the deterioration and depletion of natural resource base, which is further, indicated the greater heterogeneity of land use patterns (Meshesha *et al*., 2014).

The reviewed studies showed that starting from the 1957 aerial photograph (Deribew and Dalacho, 2019) to this date of high-resolution satellite imagery (Mekonnen *et al*., 2016), LU/LC assessments were done almost in all parts of Ethiopia. In the overall information extraction, good progress has been realized from simple to very complex digital methodologies (Ariti *et al*., 2015; Gidey *et al*., 2017; Gebremicael *et al*., 2018; Betru *et al*., 2019). However, none of the studies have suggested a specific methodology to a certain nature of the landscape. Moreover, some limitations are observed in their level of accuracy, which is sourced from landscape heterogeneity, imaging property, information extraction methodologies, and availability of ancillary data's. Due to the absence of well-organized and up-to-date national level geospatial database (i.e. LU/LC), Ethiopia have been costing (finance and human resources) to assess the land surface resources for different purposes from individuals thesis (Burka, 2008) to national/regional projects (WBISPP, 2004; Mekonnen *et al*., 2016; MoEFCC, 2016).

Even though LU/LCC studies have been done so far, regardless of the doubt on outputs accuracy, local natural resource managers and national policymakers are entirely dependent on the information generated from those investigations. Decisions made from that uncertain information could yield to further cost on the sustainable use and conservation of natural resources.

It is important to note that, no particular classification method is inherently superior to any others. Therefore, the overall intention of this review is (i) to compile the progress, (ii) to point out the challenges and situations where one classification method is liable to be more accurate than the other, and (iii) to examine the implications of LU/LCC studies done so far in the diverse landscape of Ethiopia. This may have a great role to be used as a baseline document of methods used to quantify LU/LCC in Ethiopia and may be used as an inspiration to develop a new methods/techniques based on the progress and challenges encountered so far in the country.

2. Definitions and Basic Concepts

2.1. Definitions

Application of remote sensing and GIS becomes the prominent tool in the scientific communities for land resource assessments. Consequently, phrases like land use, land cover, land use change, and land cover change are the common elements throughout assessing and monitoring environmental changes (Giri, 2012). Therefore, as of most studies did, it is important to define those phrases for common understanding.

Table 1. Summarized explanations of common phrases

Phrase	Description
Land cover	Land cover is the biophysical outlook of the Earth. E.g. A land covered by forests, scrubs, grass, agriculture, barren, ice and snow, urban, and water.
Land use	Land use is the function or the socioeconomic purpose of the land being used. E.g. Recreational or educational forest.
Land cover change (LCC)	LCC refers either the total conversion (forest to urban) or modification (forest degradation) of the land cover. Monitoring conversion is easier using remotely sensed data.
Land use change (LUC)	LUC is the change in the use or management of the land by the user. Sometimes, LUC may not be caused by LCC. E.g. a production forest can be declared to a recreational forest. However, LUC is likely to cause LCC.

Adapted from Giri (2012)

Despite the enactment of remote sensing technology, it is limited in defining the issue of land uses. Instead, it detects the overall reflectance of targeted land covers. That may be the reason for the use of LUC and LCC as supplemental. This is to mean LUC is possible only through ground observation or measurement but LCC uses records of the electromagnetic energy from remotely sensed imagery. Therefore, the synergy of techniques used to detect LUC and LCC objectify monitoring of environmental changes, LU/LCC (Giri, 2012).

2.2. Satellite image classification techniques

LU/LCC are sourced from satellite image processing with the aid of real ground knowledge, processing techniques, and use of the available ancillary data. This process is laid under the concept of satellite image classification which is a multidisciplinary procedure aimed to extract meaningful information from the raw data (Giri, 2012; Abburu and Golla, 2015).

According to Abburu and Golla (2015), satellite image classification process involves grouping the image pixel values into meaningful categories. It is broadly classified into three categories 1) automatic 2) manual and 3) hybrid.

In the manual approach, a human analyst attempting to classify features in an image uses the elements of visual interpretation to identify homogeneous groups of pixels, which represent land cover classes of interest. However, the automatic (digital) image classification produced a mosaic of spectrally homogeneous pixels, essentially a thematic map, of the original image (Giri, 2012).

The automatic approach can be self-executing (unsupervised) and user-driven (supervised). The former generates a cluster of pixels which needs to be further verified and labeled, while, the later needs supervision of the expert to train the software from the ground information (Abburu and Golla, 2015; Balamurugan and Jayarraman, 2016).

In the reviewed studies, various forms of hybrid classifications those combined automatic to manual techniques were identified. These are a combination of unsupervised and supervised (Teka *et al.*, 2018), unsupervised and manual (WBISPP, 2004), and supervised and manual approach (Betru *et al*., 2019). In general, for the sake of clarity, the previously mentioned hybrid approaches are grouped into successive and merged process based categories.

A cluster of spectral classes from the unsupervised classification is used as training sets to define land cover information classes for supervised classification. This is a kind of successive hybrid when the output of the primary procedure is used as an input for the next one (Gashaw and Fentahun, 2014; Teka *et al*., 2018), whereas, the other approach is a hybrid through merging technique. In this process, there is independent execution of supervised and on-screen-digitizing techniques. In the end, rule-based statement is used to merge those results for the final map (Sahle*et al*., 2016; Betru *et al*., 2019). This is achieved through automated methods to do initial classification and then further manual methods are used to refine classification and correct errors (Abburu and Golla, 2015).

Indeed, the extraction of information from image classification in remote sensing technology is dependent on the landscape heterogeneity and the data used which affects the selection and accuracy of image classification techniques. This is issue bothers an area on which the pattern and texture of the landscape cover change abruptly (Meshesha *et al*., 2014; Mekonnen *et al*., 2016). This is also a challenge in a country like Ethiopia where there is larger vegetation and landscape diversity is gifted. Therefore, the following section discusses the different LU/LC detection techniques used by various scholars in the Ethiopian landscape only.

3. LU/LC Detection Methods Used in Ethiopia

This section has summarized the different methodologies used in so far to assess the multi-temporal changes accounted in LU/LC patterns along the Ethiopian landscape. In Ethiopia, it is obviously known that most landscape heterogeneity is changed with altitudes including population density from lowland to highlands. As Burka (2008) narrated, the majority of the population of Ethiopia settled in the Ethiopian highlands, which facilitates the degradation of the environment and triggers LU/LCC faster than the lowland ecosystem. The population growth would lead to the need for new settlement areas and agricultural lands which have contributed to the deterioration of natural land covers (Meshesha *et al*., 2014). Therefore, the under-reviewed image classification techniques are also considered the texture of their area of investigation.

3.1. Unsupervised image classification

Table 2. Summary of unsupervised image classification techniques used in Ethiopia

Study area	Altitude range (m.a.s.l.)	Image/data used	Ancillary data/sand source	LU/LC and producer accuracy for the latest year (%)	Challenges/ corrections made	Source
West Shewa, Oromia	1200 – 1600	TM (1984), ETM+ (1999), and SPOT (2007)	Field observation	Shrub/grassland, Grassland, cultivated land, settlement, and a town. No accuracy report.	Individual settlements from the surrounding farm plots was not separated	Mulugeta and Weldesemait, 2011
Central Rift Valley	1572 – 2800	1973 (MSS), 1986 (TM), and 2000 and 2014 (ETM+)	Aerial photo, Google earth and field survey	Forest (96), woodland (93), grassland (88), cropland (96), water (91).	120 classes were generated and re-classed to five LU/LC types.	Ariti *et al*., 2015

Note: Producer's accuracy is computed by dividing correctly classified pixels to the total reference points of the specific LU/LC category. TM: Thematic Mapper; ETM+: Enhanced Thematic Mapper plus; MSS: Multispectral Scanner; SPOT: Satellite Pour I'Observation de la Terre.

Mostly unsupervised classification method is executed for an initial understanding of the area under study and further applied as a training cluster of pixels for other techniques (Section 3.4). However, in the above investigations (Table 2), it was used to cluster homogeneous pixels into a large number of classes and after ground information, reclassification provides the existing major LU/LC categories/classes (Mulugeta and Weldesemait, 2011; Ariti *et al*., 2015).

The prior intention of Mulugeta and Weldesemait (2011) was to map the effect of resettlement packages occurred in the area on the surrounding land use patterns. This study reveals an intensive inclusion of ground information resulted in a better detection of the existing LU/LC maps. The second study (Ariti *et al*., 2015) conducted at central rift valley (CRV), reveals an accuracy above the acceptable minimum threshold which is 85%. Confidentially, the study reasoned out that, the unsupervised techniques were recognized and clustered the spectral response patterns of the different LU/LC types of the area with the aid of efficient ancillary data's (Figure 1).

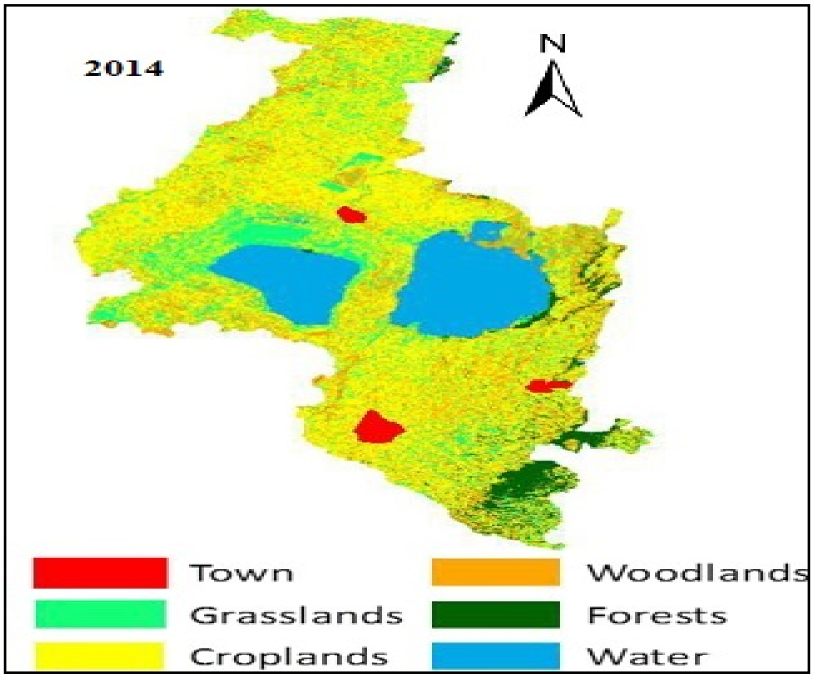

Figure 1. LU/LC maps of CRV for 2014 (Ariti et al., 2015)

3.2. Supervised image classification

Table 3. Summary of supervised image classification techniques used in Ethiopia

Study area	Altitude range (m.a.s.l.)	Image/data used	Ancillary data/s and source	LU/LC and producer accuracy for the latest year (%)	Challenges	Source
Borana rangelands, Southern Ethiopia	1000 – 1700	Aerial photographs (1967 and 1987), ETM+ (2002)	Topographic maps, aerial photographs, and field observation	Grass cover, woody vegetation cover, cultivated cover, bare land, settlement. No accuracy.	Bushes and shrubs and trees are merged in a class.	Haile *et al*., 2010
Kemekem district, Northwest Ethiopia	1900 – 2800	Panchromatic aerial photographs (1957 and 1980), ETM+ (2003)	Field survey and Topographic map	Dense forest, Cultivated and Settlement land, Woodland, Shrub land, Grassland, and Riverine vegetation. No accuracy.	Plantation vs. natural forest, rural dowelling vs. cultivated land were not separated	Molla *et al*., 2010
Northern Afar rangelands, Ethiopia	100 - 2500	MSS (1972), TM (1986), ETM+ (2007)	Field survey and Aerial photographs	Woodland (80.77), bush land (88.24), bushy grassland (78.26), grassland (100), scrubland (81.13), cultivated land (97.22) and bare land (100)	Cropping fields and settlements areas were merged together	Tsegaye *et al*., 2010
Gerado catchment, South Wollo Highlands, Ethiopia	2174 – 3032	Aerial photographs (1958 and 1980), and SPOT (2006)	Field survey and Topographic map	Cultivated and rural settlements, shrub land, woodland, bare land, grassland, urban built-up, and forest. No accuracy data	Cultivated areas and rural settlement land were not separated	Asmamaw *et al*., 2011
Borena district, South Wollo zone, Ethiopia	1000 – 4000	1972 (MSS), 1985 (TM), and 2003 (ETM+)	Field survey and Topographic map	Cropland, forest, Shrub land, grassland, bare land. No class accuracy. Overall accuracy = 86.11	Cropland vs. rural residents were not separated	Shiferaw and Singh, 2011
Semen mountains NP, Northwestern Ethiopia	1900 – 4430	1984 (TM) and 2003 (ETM+)	Field survey and DEM	Agriculture (96.3), mixed forest (100), pure forest (72.7), shrub/young trees (100), and grassland (84).	Shadow areas are left unclassified as one LU/LC category	Wondie *et al*., 2011
Midwest escarpment of Rift Valley	2000 – 2400	Aerial photographs (1972), TM (2004)	topographic map, slope map, field and household survey	Riverine trees, plantation trees, perennial croplands andsettlement, shrub/ grassland, annual crop land, and bare land. No class accuracy. Overall accuracy = 87%	Areas with enset and chat tree crops, rural settlements were detected together	Mengistu *et al*., 2012
Gish-Abay watershed, Northwestern highland, Ethiopia	2000 – 3100	Panchromatic aerial photographs (1957 and 1982), TM (2001)	Field survey	Forest and dense trees, riparian vegetation, shrub grassland, open grassland, cropland and rural settlement, and town. No accuracy	Rural settlements and surrounding farm plots couldn't separated	Bewket and Abebe, 2013

				report.		
Arsi-Negele Districts, Ethiopia	1500 – 3400	MSS (1973), TM (1986), ETM+ (2000), and Rapid Eye (2012)	DEM, Aerial photo, NDVI, Topo map, field survey, other administrative and infrastructure data.	Bare lands (90), grasslands (88.7), water (100), settlements (94.4), croplands (81.6), tree patches (96.9), plantation forests (96.4), natural forests (98.2), woodlands (97.9)	Image segmentation – classification – merging were done in turn to map LU/LC and avoid errors	Kindu *et al.*, 2013*
Koga catchment, Northwestern Ethiopia	1500 – 2400	Aerial photographs (1957), MSS (1979), TM (1986), ETM+ (1999), and ASTER (2010)	Field survey, elder's interview, topographic map and aerial photo	Woody vegetation, pasture, crop field, bare land, settlement, and water. No class accuracy. Overall accuracy = 99.48	Trees and shrubs $\geq$20% crown cover and taller than 2m were detected as woody vegetation	Yeshaneh *et al.*, 2013
Bantneka Watershed, Southern Ethiopia	1750 - 2200	TM (1986), ETM+ (2000), and SPOT (2006)	Field survey, interview and discussion, topographic map	Annual cereal crop land, mixed land, perennial crop land, woodland and settlement land. No accuracy report.	Coffee and Enset were not separated from large indigenous trees and perennial fruit trees.	Fentahun and Gashaw, 2014
Ameleke watershed, South Ethiopia	1200 – 2000	TM (1986), ETM+ (2000), and SPOT (2006)	Field survey, topographic map and elder's interview	Agroforestry, crop land, grass land, mixed cover, shrub land, and riverine forest. No class accuracy. Overall accuracy = 85.71	Some areas (1.16%) were unclassified. Resident areas weren't detected.	Worku *et al.*, 2014
Nech Sar National Park, South Ethiopia	1100 – 1650	TM and ETM+ (1985, 1995, 2005 and 2011) Sensors are not indicated separately.	Field survey, elder's interview, and NDVI	Forest (90), grassland (94), encroaching plants (92), wooded grassland (80), woodland (86), cultivated (85) and bush/shrubs (98)	------------	Fetene *et al.*, 2015
Libokemkem District, South Gondar, Ethiopia	------------	MSS (1973), TM (1985 and 1995), ETM+ (2003), and OLI (2015)	Field visits, interviews, Google Earth image, black and white aerial photograph, and raw images	Agricultural lands (92), wetlands (96.7) degraded land (88.9), settlements (88), bush/shrub lands (78.7), grasslands (76.3), and forest land (100).	------------	Demissie *et al.*, 2017
Mekelle City, northern Ethiopia	1930 – 2353	TM (1984, 1994, and 2004), and OLI (2014)	Topographic maps, aerial photographs, Google Earth, field observation	Agricultural land (91), Built-up (94), plantation (87), shrub land (85), water body (-).	Grazing lands and crop lands were combined together.	Fenta *et al.*, 2017
Raya, Northern Ethiopia	324 - 4129	TM (1984 and 1995), and OLI (2015)	Field survey	cropland (90), forestland (88.5), shrub/bush (95), built-up area (93.3), water bodies (100), grassland (84), barren land (85.5)	Sparse rural resident are ignored. Shrubs, bush lands and riverine trees are merged.	Gidey *et al.*, 2017

				and floodplain area (88)		
Gelana sub-watershed, Northern highlands of Ethiopia	1365 - 3328	Aerial photo (1964 and 1986) and OLI (2014)	DEM and Field survey	Forest (85.5), shrub land (81.5), cultivated and rural settlement land (80.8), grass land (84.8), bare land (86.7), urban built up (92.9), wetland (92)	Cultivated and rural settlement is merged. On-screen digitizing is was to detect LU/LC from aerial photo's	Miheretu and Yimer, 2017
Yezat Watershed, North Western Ethiopia	1485 – 3207	TM (2001), ETM (2010), and OLI (2015)	DEM, topographic map, NDVI and field survey	Crop land, grassland, woodland, shrub/bush land, and homesteads. Overall accuracy = 93.2.	---------------------	Tadesse *et al.*, 2017
Keleta watershed, Awash River basin, Ethiopia	1583 – 4199	TM (1985, 1998 and 2011)	topographic map, field survey	Degraded land (81.3), farm and settlement (85.7), forest (92.2), grasslands (84.8), shrubs (93.4)and water (92.9)	Merging of annuals and perennials crop lands and scattered rural settlements	Bekele *et al.,* 2018
Chilimo forest, Central Highlands of Ethiopia	2170 – 3054	MSS (1973), TM (1984 and 98), ETM+ (2008) and OLI (2015)	Field survey for 2015 map	Shrub land (80), Rural settlements (40), Bare land (80), Forest land (95.89) and Agricultural land (86.49)	Broader LU/LC categories were privileged the result	Siraj *et al*., 2018
North-eastern Addis Ababa, central highlands of Ethiopia.	2244 – 3240	Aerial photographs (1957), MSS (1975), TM (1995) and Sentinel-2 (2017)	DEM, topographic map, Google Earth, and Field survey	Water body (100), Agricultural land (98.3), Settlement (98.3), Forest (98.3), and Bare land (96.7)	Agricultural and grazing lands are together. To tackle LU/LC confusions:**	Deribew and Dalacho, 2019*

Note: most aerial photographs used as a time series data was interpreted using on-screen-digitizing technique. OLI = Operational Land Imager; DEM = Digital Elevation Model; NDVI = Normalized Difference Vegetation Index; *refers studies used Object Based Classification (OBC) through image segmentation which is considered as supervised classification by Abburu and Golla (2015). **effected indexes like bare-area index, built-up-area index, normalized vegetation index, and masking out settlements and agricultural lands were employed to refine confusions on supervised approach.

Most of the studies in the above Table (3) were limited in detecting rural residents from cultivated lands. Unlikely, cropland with grazing land (Fenta *et al*., 2017) and coffee with Enset and large indigenous trees and perennial fruit trees were not separated (Fentahun and Gashaw, 2014; Bekele *et al.,* 2018). Majority of the studies have used broader LU/LC categories which are assumed to be caused by the coarse image resolutions and confusion of reflectance. Indeed, object-based classification techniques revealed a positive return in detecting detail LU/LC categories in Arsi-Negele and north-eastern Addis Ababa areas (Figure 2) (Kindu *et al*., 2013; Deribew and Dalacho, 2019).

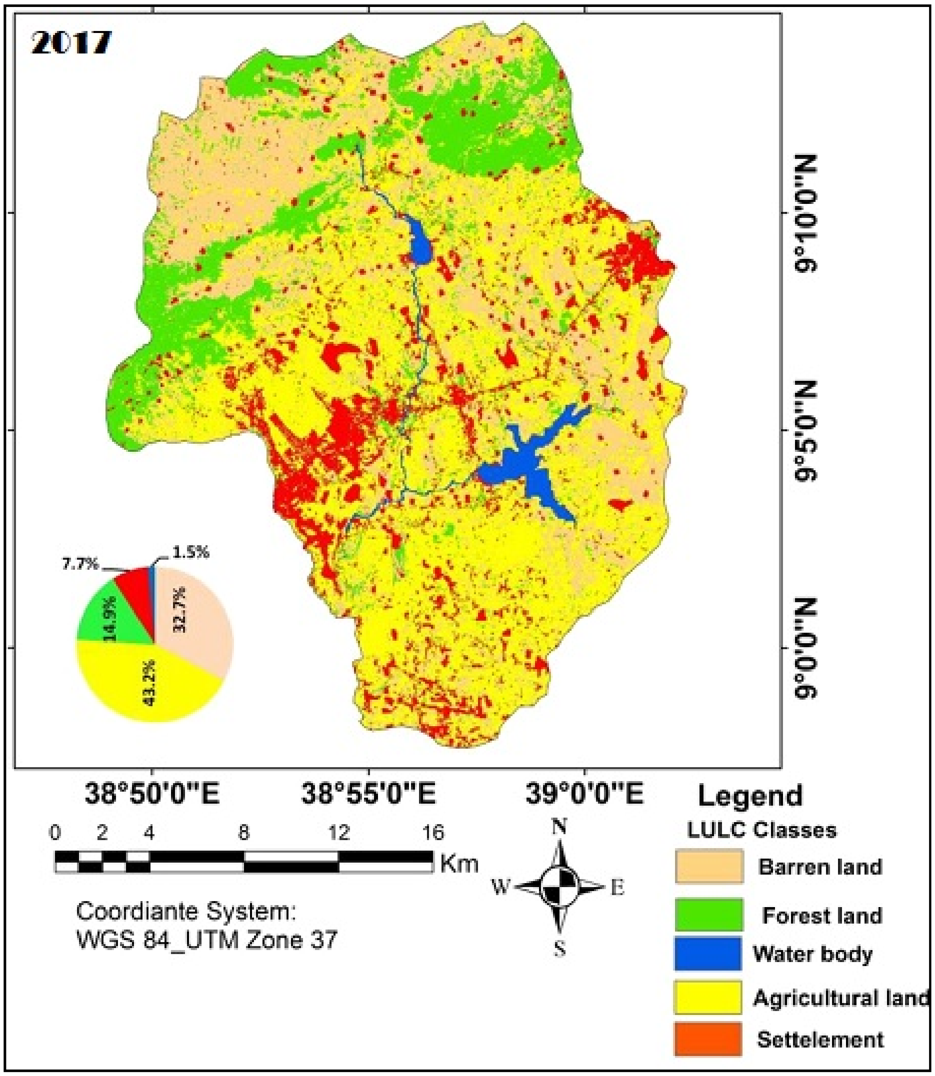

Figure 2. LU/LC map of North-eastern Addis Ababa for 2017 (Deribew and Dalacho, 2019)

3.3. Visual image interpretation

Table 4. Summary of visual image classification techniques used in Ethiopia

Study area	Altitude range (m.a.s.l.)	Image/data used	Ancillary data/s and source	LU/LC and producer accuracy for the latest year (%)	Challenges	Source
Ghibe valley, Southwestern Ethiopia	1400 - 1800	Aerial photographs (1957 and 1973), TM (1987 and 1993)	Topographic map, field survey, and elders interview	Smallholder cultivation, large holder cultivation, riverine forest, wooded grassland. No accuracy report	Larger LU/LC category leads absence of information for the smaller LU/LC classes.	Reid *et al.*,2000 Stereoscope + on-screen-digitizing
Dembecha area, Northwestern highlands of Ethiopia	1800 - 2800	Aerial photo (1957 and 1982), satellite image (1995)	Topographic map and field survey	Cultivated land, Natural forest, Plantations, Grassland, Temporary grassland, Bush land, Shrub land, Bare land, Grass- and bush land, Grass-, bush land and bare land, Small towns. No accuracy report	Cultivated land mixed with bushes and trees, and rural homesteads are categorized under Cultivated land	Zeleke and Hurni, 2001 on-screen-digitizing
Chemoga Watershed, Blue Nile Basin, Ethiopia	2420 - 4000	Panchromatic aerial photographs (1957 and 1982), SPOT (1998)	Topographic map, field survey, and discussion	Forest, woodlands, shrub lands, farmland and settlements, grassland and degraded land, Riverine trees, marshland, and pond. No accuracy report.	Dispersed rural settlements and cultivated land was not separated.	Bewket, 2002 on-screen-digitizing
Derekolli Catchment, South Wello Zone, Ethiopia	1600 - 1800	Aerial photographs (1957 and 1986), TM (2000)	Topographic map, field survey, and discussion	Shrub land, shrub-grassland, grassland, valley-rim vegetation, cropland, all-weather road, dry-weather road, and town. No accuracy.	Dispersed rural settlements were not detected.	Tegene, 2002 on-screen-digitizing
Begasheka Watershed, Tigray, Ethiopia	1739 - 1862	Field resource sketch – digitized into map – validated at field – corrected, accepted and analyzed.		Arable land, Forest land, and Grazing land.	It was based on local community knowledge about the area.	
Eastern Tigray, Ethiopia	2040 - 2840	Aerial photographs (1965 and 1994), TM (2000/5)	Topographic map, DEM, NDVI, field survey, and group discussions	Intensively cultivated land, Moderately cultivated land, Sparsely cultivated, Dense forest, and other 13 classes. No accuracy report.	Large number of LU/LC types supported by intensive ground survey was used to reduce confusions.	Alemayehu *et al.*, 2009 stereoscope + on-screen-digitizing
Central Rift Valley	Below 1800	MSS (1973), TM (1986), ETM+ (2000)	Topo. map, field survey	Cropland, cropland with trees, perennial crop, grassland, wet-	Annual rain-fed crop lands with sparsely	Garedew *et al.*, 2009

of Ethiopia				grassland, wooded-grassland, woodland, shrub land, and bare land.	stocked trees are merged together with settlements areas.	on-screen-digitizing
Northern Ethiopia	2146 - 2218	Aerial photograph (1964 and 1994), and field survey (2006)	Topographic map, field survey, and elder's interview	Forest land, cultivated land, plantation, area exclosure, woodland, shrub land, grazing land, water body, settlement.	----------------------	Gebresamuel *et al.*, 2010 On-screen-digitizing
Debre-Mewi watershed, Blue Nile Basin, Northwest Ethiopia	2200 - 2360	Panchromatic aerial photographs (1957 and 1982), TM (2008)	Topographic map, field survey, and focus group discussion	Natural forest, Shrub and bush land, Grazing land, Cultivated and settlement land, Eucalyptus plantation, and Rock outcrop. No accuracy report.	Map was generated based on field information and again validated with the local informant's	Fisseha *et al.*, 2011 stereoscope + on-screen-digitizing
Mandura district, Northwestern Ethiopia	1015 - 1480	Aerial photographs (1957 and 1982), and SPOT-5 (2006/07)	Topographic map, field survey, interview, and focus group discussion	Forests, woodlands, shrub lands, grassland with scattered trees, bare land, riverine trees, farmland, and settlement	Rural homesteads were included under farm land	Emiru and Taye, 2012 on-screen-digitizing
Bahir Dar, Ethiopia	average = 1801	Aerial photographs (1957, 1984and 1994)	Field survey and mapping	Built-up area, forest land, water bodies, agricultural land. No accuracy report. Overall accuracy = 87	----------------------	Haregeweyn *et al.*, 2012
Tigray province, northern Ethiopia	500 - 4000	Aerial photographs (1965 and 1994), and IKONOS and Quickbird (2007)	Field survey, interview, and group discussion	Arable land, Bare land, grass land, built-up area, shrub land, bush land, forest land, and water body. No accuracy report.	----------------------	Teka *et al.*, 2013 on-screen-digitizing
Eastern highland of Ethiopia	1980 - 2343	TM (1985, 1995, 2006, and 2011)	Topographic map, aerial photos, and field survey	Grassland (85), degraded land (86), marsh area (75), perennial cropland (93), plantation (89), residential (89), shrub land (85), water bodies (-), woodland (83), and temporal cropland (89)	Time taking, tedious, and vulnerable to errors.	Meshesha *et al.*, 2014 On-screen-digitizing
Eastern Tigray, Ethiopia	2300 - 3000	Aerial photographs (1965 and 1994),	Field survey and informant's	Arable land, bare land, grass land, built-up area, shrub land, bush land,	----------------------	Belay *et al.*, 2014 On-screen-

		IKONOS (2007)	interview	forest land, and water body. No class accuracy report.		digitizing
Hirmi watershed, Northern Ethiopia	1800 - 2500	Aerial photographs of 1964 and 1994, and SPOT-5 (2006)	Topographic map, key informant's interview, and group discussion	Forest, grassland, cultivated and rural settlement, town, shrub land and an artificial pond. No class accuracy report.	Rural settlement and cultivated land cover units were also grouped under the same category	Gebrelibanos and Assen, 2015 stereoscope + on-screen-digitizing
Amhara Region, Ethiopia	-------------	SPOT-5 image	Field survey, key informant's interview, and discussion	Forest types of the region: Woodlands, natural dense forest, plantation, open woodland, riverine forest	Time taking, needs experts' agreements. Intensive field work done to reduce errors.	Mekonnen *et al.*, 2016 on-screen-digitizing

Majority of studies that used visual image interpretation technique argued for the accuracy of the automatic image classification approach. For instance, Meshesha *et al*. (2014) has first employed automatic one and observed a significant level of errors occurred due to landscape heterogeneity then visual image interpretation was used to generate the LU/LC maps (Fihure 3). However, despite the higher accuracy level and simple software requirements of visual image interpretation, it needs large number of trained manpower, higher cost, exhaustive time, and fine resolution data for larger and heterogeneous areas (Büttner, 2014; Zhang *et al.,* 2014; Mekonnen *et al*., 2016; Sahle*et al*., 2016; Betru *et al*., 2019).

Almost all of the above studies have agreed on the performance of manual (on-screen-digitizing) method. In-depth, this approach is robust, effective and efficient methods. Efficiency and accuracy of this approach is depending on analyst knowledge and familiarity towards the field of study. The analyst needs to know aspects of the study area in addition to the spectral response of the image. Even though there were purposive class-categories are applied, the researcher's need to have appropriate support data and skill for accurate and reliable resource mapping (Meshesha *et al*., 2014; Mekonnen *et al*., 2016).

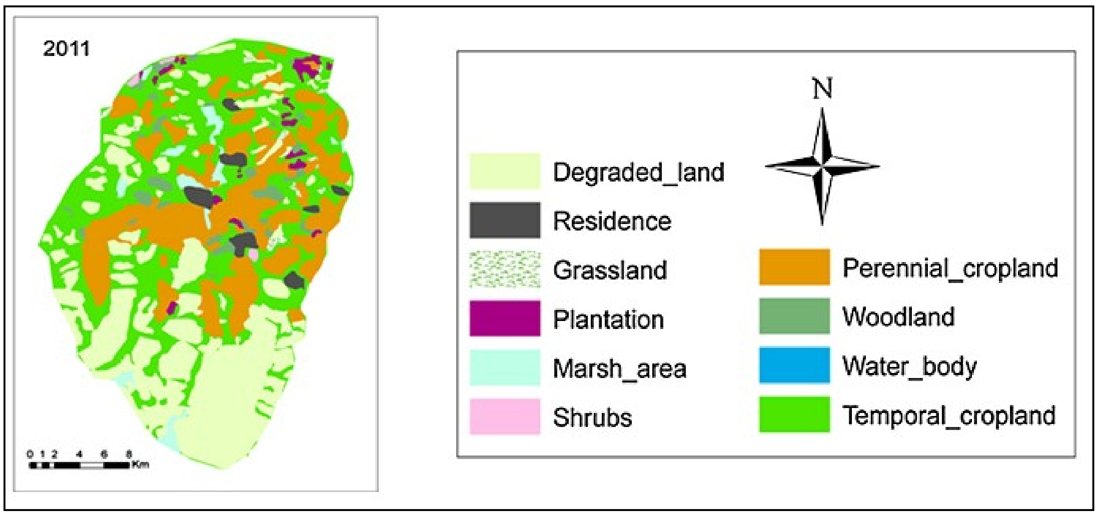

Figure 3. LU/LC map of eastern highland Ethiopia (Meshesha et al., 2014)

3.4. Hybrid image classification

Table 5. Summary of hybrid image classification techniques used in Ethiopia

Study area	Altitude range (m.a.s.l.)	Image/data used	Ancillary data/s and source	LU/LC and producer accuracy for the latest year (%)	Challenges/ corrections made	Source
Jedeb watershed, Upper Blue Nile, Ethiopia	2172 – 4001	Aerial photograph and MSS (1972), TM (1986 and 1994). TM and ASTER (2009)	Aerial photograph, SPOT image, and field survey	Grassland (97), afro alpine grassland (94), cultivated land (99), shrubs and bushes (86), woodland (80), plantation forest (88), ericaceous forest (75), marshland (97), and barren land (89).	Urban and marshlands land was digitized and masked out from the image to tackle signature confusion among marshland and grassland, urban land and barren land and cultivated land.	Teferi *et al*., 2013 *unsupervised± supervised*
East of Lake Tana, Ethiopia	1779 – 1846	TM (1985) and ETM+ (2011)	Topographical map, field observation, group discussion	Cultivated land, forest land, shrub land, grass land, water body and degraded land. No class accuracy. Overall accuracy = 80	Cultivated land mixed with some bushes, trees and the scattered rural settlements included within the cultivated fields.	Gashaw and Fentahun, 2014 *unsupervised± supervised*
Dera District, Ethiopia	1798 – 2118	TM (1985)and ETM+ (2011)	Field observations, NDVI, Toposheet	Forest land, shrub land, grass land, cultivated land, degraded land and water body. No class accuracy. Overall accuracy = 84	Cultivated land mixed with some bushes, trees and the scattered rural settlements included within the cultivated fields.	Gashaw *et al*., 2014 *unsupervised± supervised*
Lake Hawassa Watershed, Ethiopia	1571 - 2962	MSS (1973), TM+SPOT (1985), and TM (1995 and 2011)	Aerial photographs, and topographical maps, SPOT image, and field survey	Water (94.3), built-up (84.1), cropland (84.3), woody vegetation (81.4), forest (87.1), grassland (75), swamp (88.9), bare land (87.5), and scrub (86.8)	Scattered trees, Khat and Coffee are merged under woody vegetation. Images was segmented and clustered to identify the range of training areas for supervised classification.	Wondrade *et al*., 2014 *unsupervised (Segmentation) ± supervised*
North Western Lowlands, Ethiopia	500 - 1849	TM (1985, 1995, and 2010)	Topographic map, Google Earth, and Field survey	Wood land (86.5), shrub/bush land (85.3), Grass land (81.86), Agricultural land (90.45), Bare land and settlement (84.08), water body (100).	Patches of trees are compiled in to two categories (grass lands and shrub/bush land. Bare land and settlement were not separated.	Alemu *et al*., 2015 *unsupervised± supervised*

Infraz watershed, NW Ethiopia	1777 – 2110	MSS (1973), and TM (1986, 1995 and 2011)	Field survey, topographic map, SPOT image and Google Earth	Forest, agriculture and settlement areas, bush lands, grass lands and wetlands. No class accuracy. Kappa Statistics = 0.86	Agriculture and settlements were merged and swamps, ponds, riparian vegetation and marsh areas were also merged.	Sewnet, 2015 *Unsupervised ± supervised*
Batena watershed, Rift Valley Lakes, Southwestern Ethiopia	2063 – 2947	MSS (1973), TM (1984), ETM (1995), ETM (2003), and ETM (2008). *TM and ETM was pan-sharpened*	NDVI and field survey	Agricultural land, grazing land, scrub lands, mixed forest, and water body. No class accuracy. Overall all accuracy = 76% and Kappa statistics = 0.67	Scattered rural settlement were included under agricultural land.	Ayele *et al*., 2016 NDVI± unsupervised ± supervised
South Central Ethiopia	1600 - 3100	MSS (1972), TM (1984 and 1994), ETM+ (1999 and 2013), OLI (2013)	Aerial photo. And topo. maps, DEM, Landsat image composites, Google Earth, and field observation / group discussions	Agriculture (0.8), irrigation (1), greenhouse (1), grassland (0.55), forest / woodland (1), trees outside forest (0.89) lake / reservoir (1), swamp (1), bare land (1), and built-up (0.79).	Rule based corrections were made to refine classification errors by merging the outputs of the visual and supervised method.	Sahle *et al*., 2016 *Supervised + Visual (on-screen-digitizing)*
Tekeze-Atbara Basin, Ethiopia	930 - 3300	MSS (1972), TM (1989), ETM+ (2001), and OLI (2014)	Aerial photo, topographic map, Existing LU/LC map, DEM, field survey, and elder's interview	Grassland, agriculture, bushes and shrubs, wooded bushes, settlement, water body, bare land, forest land, and plantation forest. The overall accuracy = 84.3 and Kappa coeff. = 81.1%	ISODATA algorithm and several GTP has enabled detail LU/LC detection	Gebremicael *et al*., 2018 *Unsupervised ± supervised*
Borana rangelands, Southern Ethiopia	1000 – 1600	MSS (1973), TM (1986) and ETM+ (2003)	NDVI and field survey	Woodland, grassland, bare land, cultivated/built-up area. No class accuracy. Overall = 69.5	Crop lands and settlements areas were not separated.	Teka *et al*., 2018 *Unsupervised ± supervised*
Assosa Zone, Western Ethiopia	613-1641	MSS (1978), TM (1986, 1991 and 2010), ETM+ (1999) and OLI (2013 and 2016)	Field survey, key informant interview, focus group discussion, DEM, Google earth/ Engine, Landsat image composite	Forest (96.7), Agriculture (96.0), Shrub/grass (84.3), and Settlement (94.9). Over all = 93.57	Wrong classification (caused by spectral confusion) outputs in the supervised techniques was refined based on visually interpreted map.	Betru *et al*., 2019 *Supervised + Visual (on-screen digitizing)*

Note: Most aerial photographs used as a time series data was interpreted using on-screen-digitizing technique.
The hybrid forms successive (±), merged (+) were considered the way how the classification techniques used for final LU/LC map

As stated in the above Table (5), except Sahle *et al*. (2016) and Betru *et al*. (2019), all of the studies used the successive operation of unsupervised and supervised classifications. The combination of automatic techniques has a great role in detecting the spectral responses of features but commonly vulnerable to errors and limited where spectral confusions exist. The researchers' suggested that, in order to reduce classification errors, it is better to use a combinations approach than a reliance on a single technique. Unlikely, Sahle *et al*. (2016) and Betru *et al*. (2019) pointed out limitation on the automatic techniques. Instead, these studies recommended combining the digital system with the manual approach through merging technique to refine classification confusions and generate reliable LU/LC information.

4. Progress and Challenges in LU/LC Detection Methods

The growing necessity of land cover changes for a wide range of applications makes the global environmental changes assessment to rely on remote sensing data. These phenomena engaged many scholars in developing from simple to complex satellite image classification methods.

In the past two decades, from the earliest stereoscope and/or on-screen-digitizing (Reid *et al*., 2000) to the recently emerged hybrid of automatic and manual (Teferi *et al*., 2013; Sahle *et al*., 2016) as well as object-based classification (OBC) (Kindu *et al*., 2013) technique were executed and found to be a pioneers in Ethiopia. However, the majority of the studies were relied on supervised classification preceded to the visual interpretation which show change in LU/LC types in the country.

Indeed, visual interpretation has remained an exceptional technique for aerial photographs. Later, it is widely adopted for satellite imageries with the need of medium to high-resolution data. Nowadays, it is used independently (Mekonnen *et al*., 2016) also involved in the hybrid and OBC approaches (Betru *et al*., 2019; Deribew and Dalacho, 2019). In overall, the progress on information detection showed a great improvement in detail of resource assessment and reducing labor consumption through digital procedures. On the other hand, there is an increasing doubt on the efficiency of the techniques on different landscape conditions.

The first and the prominent challenge observed was the data quality (spatial-resolution) to magnify the spatial variability of the landscape features. In this regard, among the 50 reviewed studies, the majority has used medium resolution images from open-sourced Landsat generations.

However, some studies those effected manual technique has privileged the classification detail using high-resolution images from other sensors (Mulugeta and Weldesemait, 2011; Teka *et al*., 2013; Belay *et al*., 2014; Fentahun and Gashaw, 2014; Gebrelibanos and Assen, 2015; Mekonnen *et al*., 2016; Deribew and Dalacho, 2019). However, the central concern is the efficiency of the aforementioned techniques under similar data characteristics whereas in diverse landscape patterns.

Due to the spectral confusion between the reflectance of different land surface features, the supervised and unsupervised methods are in a doubt by their inefficiency to separate diverse composites of land surface features when applied separately (Wondrade *et al*., 2014). However, with exhaustive ancillary and reference data, supervised technique revealed promising results around south Gondar (Demissie *et al*., 2017). In meanwhile, to overcome the inherent limitation, the combination of them (hybrid) was employed from low-to-highland areas of the country (Teferi *et al*., 2013; Teka *et al*., 2018). This approach achieved better accuracy than using them alone. As far as the reflectance values are in focus, still misclassification of some land covers those have similar spectral reflectance was observed as a challenge.

In addition, visual interpretation (on-screen-digitizing) was also revealed as a better technique for heterogeneous land surface features through medium to high resolution satellite imagery. Nevertheless, it needs a large number of trained manpower, higher cost, and exhaustive time (Meshesha *et al*., 2014; Mekonnen *et al*., 2016). Complete execution of on-screen-digitizing losses the digital response values of surface features. As indicated in Sahle *et al*. (2016) and Betru *et al*. (2019), the combination of automatic techniques with manual mapping were another option to detect the spectral responses and the real outlook of surface features. Both of these studies recommended this approach to refine classification errors and generate reliable LU/LC information's.

The accuracy of LU/LC map largely depends on image classification methods and reference data is used. Most studies recommended that reference data be like an aerial photograph, topographic map, and other soft information are required in accordance with the characteristics of the landscape. To support the LU/LC mapping, Sydenstricker-Neto *et al*. (2004); Sahle *et al*. (2016) and Betru *et al*. (2019) acknowledged collection of reference points using participatory approach integrated with composite satellite imagery in the absence of historical aerial photographs.

5. Implications of LU/LC Detection Methods

Information is a primary impute to identify existing problems and its prioritization to set appropriate interventions. In Ethiopia, almost all of the existing LU/LC assessment methods are applied to extract information from remote sensing data by different researcher and organizations. Despite the reliability of the output, the absence of an up-to-date national database caused for routine and disintegrated investment for different purposes at different time.

For instance Woody Biomass Inventory and Strategic Planning Project (WBISPP, 2004); Ethiopia's forest reference level submission to the UNFCCC published by Ministry of Environment, Forest, and Climate Change (MoEFCC, 2016); and a report on causes of deforestation and forest degradation in Ethiopia (MoEF, 2015a) are the main countrywide projects engaged in forest and related resource assessments. A successive hybrid of unsupervised and visual interpretation, unsupervised classification, and supervised classification are the different techniques used by the projects, respectively. Similar to LU/LC map of Europe (Büttner, 2014) and China (Zhang *et al*., 2014), forest resource map of Amhara regional state of Ethiopia was quantified using only visual image interpretation with maximum accuracy (Mekonnen *et al*., 2016). Those projects were aimed to enrich the spatio-temporal resources database under a certain time for different purposes.

There are also numerous studies conducted and used LU/LC information as an input for further modeling purposes, for instance hydrological modeling (Gashaw *et al.,* 2018), soil erosion mapping (Gessesse *et al*., 2015), ecosystem service modeling (Tolessa *et al.,* 2017), wildlife and biodiversity monitoring (Mengesha *et al.,* 2014), climate change modeling (Reid et al., 2000), ecotourism potential area mapping (Nino *et al.,* 2017), its impact on forest resources and soil quality (Bessie *et al*., 2016; Teferi *et al*., 2016),watershed prioritization/land use planning, and etc. Those studies employed the most common types of image classification approaches.

Zhang *et al.* (2014) of China and Meshesha *et al*. (2014) of Eastern Ethiopia confirmed the validation of automatic classification methods which provide satisfactory results at smooth landscape patterns. Therefore, the independent application of digital classification methods makes difficult land cover identification in areas where larger biophysical heterogeneity and inconsistent variability of land cover patterns exists like in Ethiopia. Its accuracy may depend on the extent of fieldwork done and ancillary data's used. In order to generate reliable information, a consensus should be made on the mapping technique which aimed to set a landscape based methodologies.

According to the review of REDD+ report, the status of forest resource of Ethiopia is narrated at different periods in 1900 (40%), 1954 (16%), 1961 (8%), 1975 (4%), 1980 (3.6%), 1998 (2.7%), and 2015 (15%) (MoEF, 2015b). Forest cover increment in 2015 was due to the addition of dense woodlands, bamboo forest, natural and plantation forest as "Forest" cover. But according to the 2015 estimate of Global Forest Resources Assessment, Ethiopia's forest resource was accounted as 11.4% of its total land mass (FAO, 2015). This variation in forest cover estimation is mainly reliant on the working definitions and methods of detecting forest cover. This problem has a larger influence on the resources utilization and conservation planning and carbon credits of the country. This was the rationale for revision of national forest definition. According to this estimate, 15.5% of Ethiopia's landmass was covered by forest (MoEFCC, 2016).

6. Conclusion

Ethiopia is diverse in vegetation types/species and land use system along with a range of altitudes and population distribution. In Ethiopia, many scholars, and governmental and non-governmental organizations have undertaken land resources assessment tasks. Historical and recent scenarios of LU/LC studies were done in almost all parts of the country. All of the studies revealed a continued change in all LU/LC types.

Due to the lack of commonly accepted LU/LC detection approaches and database, the progress of detection techniques were observed from simple to more detail approaches and their accuracy level. Nevertheless, most of the existing findings have a doubt in the reliability of achieved accuracy level. Almost all of the studies have some sort of challenges in detecting the existing land resource features.

The inclusion of exhaustive ancillary data's and ground information is a common element for image interpretation. Integration of one or more image classification techniques revealed a better accuracy and detail of information than independent application. To this end, object-based classification and a hybrid of on-screen-digitizing and automated techniques are the recent and most promising approaches to handle spectral confusions and incorporate reflectance values with actual field outlooks (visual elements). Afterward, site-specific methodologies are prominently required to avoid over-/under-estimation and extract reliable land resources information.

Therefore, providing information on LU/LCC is vital to monitor resources over time. Gathering such information could be an input for further studies and contribute to policymakers with insights to make an informed decision over land use planning and enhancing farmer's livelihoods through proper support.

There should be an up-to-date national database which can organize and publicize available studies that have better level of methodological acceptance and reliable results. The national database is also expected to coin fragmented studies, undertake, and report timely resource assessment activities. This will help to reduce the cost and recourse of studies done by different scholars, for different purposes at different parts of Ethiopia. On the other hand, in-depth comparison of LU/LC detection techniques under different landscapes of the country will signify efficient site specific methodology. Therefore, to fill the gap, in-situ image processing is recommended for further investigation.

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Impacts of Climate Change on Crop Production and Its Adaptation and Mitigation Strategies in Ethiopia

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Received: September 22, 2018 Accepted: May 12, 2019

Abstract: *Agriculture is the foundation of Ethiopia's economy where crop production contributes more than 65% of the agricultural GDP of the country. The impacts of climate change have been observed in Ethiopia over a long period of time which changes the environmental conditions that influence the livelihoods of the farmers and thus the national economy. Future climate projections showed continuing warming of the environment with varying rainfall patterns. The rain fed crop production, which is mostly practiced in the country, is highly vulnerable to climate change. The purpose of the present review is therefore, to review the impacts of climate change on crop production of Ethiopia and its adaptation and mitigation strategies. According to the results of the review, the main climate change hazards observed in Ethiopia are associated with rainfall variability including the amount, timing and intensity. Rainfall variability and recurrent drought lead to frequent yield losses and in sever conditions crop failures that result losses of property and even human life in the country. Smallholder farmers in the country are trying to use indigenous and improved crop production technologies as well as different management practices including selection of crops and or cultivars suitable to changing climate, adjustment of frequency and time of tillage, optimization of time of planting and its density, intercropping, traditional irrigation and water harvesting technologies. Rigorous natural resource management strategies including afforestation, promotion of agro-forestry, and use of renewable energy sources and development of land use plan were among others mitigation strategies of climate change implemented in the country. Capitalizing the existing development policies and programmers, development of research and extension services, improving the linkages between the respective stakeholders and awareness and understanding of local communities about the relationship between climate change and crop production are recommended to reduce the impacts of climate change on crop production of the country.*

Keywords: Crop failure, rainfall variability, recurrent drought, water harvesting, yield loss

1. Introduction

Agriculture contributes a remarkable proportion to the Ethiopian national economy, and the gross domestic product (GDP) is highly dependent on the performance of the agriculture sector. In recent years, a slight structural change from agriculture to the non-agriculture sector, specifically to the service sector, has been observed. The contribution of agriculture to GDP declined from 57% to 41% between 1996 and 2010 (Adefris *et al*., 2013). Though its contribution is decreasing, agriculture is still important as it contributes to economic growth of the country. It supplies raw materials to the industrial sector and 85% of the population is engaged in the sector. Moreover, agriculture contributes nearly 90% to Ethiopia's export earnings (FDRE, 2010).

Among the agriculture sector, crop production constitutes more than 65% of the agricultural GDP. However, climate change affects crop production of the country over a long period of time through changing rainfall distribution, increasing temperature and degradation of soil nutrients (reference). Climate projections show continued warming with very mixed patterns of rainfall change. Whenever the rainfall varies slightly, crop production and availability of food suffer considerably. Production and productivity of crops in Ethiopia is constrained mainly due to poor land use, overgrazing, poor marketing structure, inadequate transport network and low use of agricultural inputs (Adefris *et al*., 2013).

Ethiopia's history is associated often with major natural and man-made disasters that have been affecting the population from time to time. The country is therefore extremely vulnerable to drought and other natural disasters such as floods, heavy rains, frost and heat waves. Recurrent drought, famine and floods are the main problems that affect millions of people in the country. While the causes of most disasters are climate related, the deterioration of the natural system due to uncontrolled human activities and poverty has further exacerbated the situation (NMA, 2007).

As Ethiopian crop production is heavily dependent of natural rainfall, it is liable to the impacts of climate change. According to Nelson *et al*. (2009), the impacts of climate change on agriculture and human well-being can be expressed in various aspects. Among others, biological effects on crop yields, impacts on prices, production, and consumption as well as impacts on per capita calorie consumption and child malnutrition are the most important once. Therefore, climate change influences the efforts of the people to increase food production and thus reduces food security (IPCC, 2007). Therefore, the objective of this manuscript is to identify the impacts of climate change on Ethiopian crop production system so that to devise adaptation and mitigation strategies in order to combat food security problems in the country.

2. Climate Change in Ethiopia

According to National Metrological Agency [NMA] (2007), the environmental fluctuation has become a key issue in Ethiopia in the last few decades. The main climatic hazards in Ethiopia are expressed in terms of droughts and flooding. The most prominent trend in this regard is the tendency of lower rainfall during the main growing seasons in the country, which is occurring in the months of March to May and December to February. According to Adefris *et al*. (2013), rainfall declines by 15%, this is associated with anthropogenic warming of the Indian Ocean. Moreover, the onset of rainfall in the country is shifted (Adefris *et al*., 2013).

Historically, flood has never being taken as a major economic hazard in Ethiopia. However, flood occurred during the years of 1997 and 2006 were signs of climate change, which incurred significant socio-economic disruption in the country (NMA, 2007). According to NMA (2007), the country has experienced both warm and cool years over the last 55 years. In recent years, however, temperature showed an increasing trend as indicated in Figure 1. Over the last decades, the temperature in Ethiopia has increased by 0.2°C per decade. The increase in minimum temperature is pronounced with roughly 0.4°C per decade (Brohan *et al*., 2006).

On the other hand, precipitation remained fairly stable over the last 50 years when averaged over the country. The spatial and temporal variability of precipitation is relatively as indicated in Figure 3 (NMA, 2007), is high, thus large-scale trends do not necessarily reflect local conditions (Conway *et al*., 2009). According to NMA (2007), years like 1952, 1959, 1965, 1972, 1973, 1978,1984, 1991, 1994, 1999 and 2002 were dry while 1958, 1961, 1964, 1967, 1968, 1977, 1993, 1996, 1998 and 2006 were wet which were associated with El Niño and La Niña phenomena.

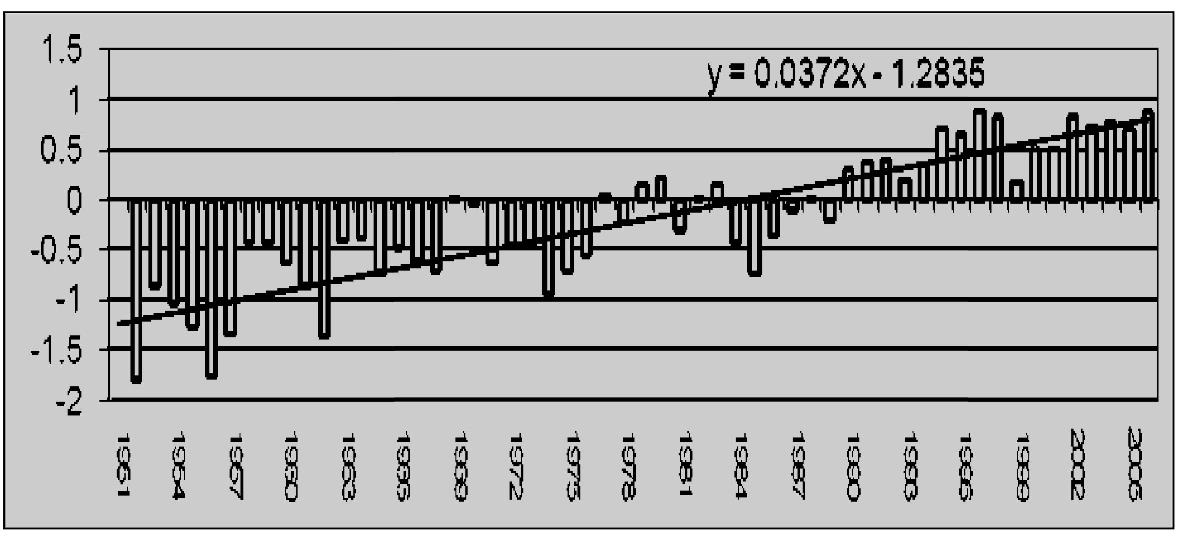

Figure 1. National average annual minimum temperature difference compared to 1971-2000 normal (NMA, 2007)

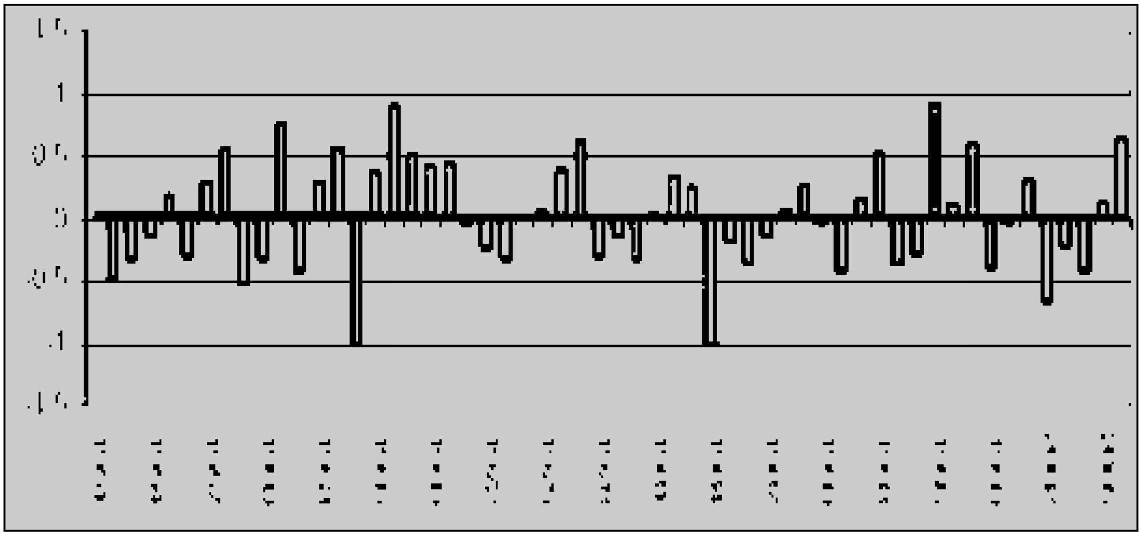

Figure 2. National average of standardized annual rainfall anomaly compared to 1971-2000 normal (NMA, 2007)

The future changes in precipitation and temperature in Ethiopia as projected by various global climate models are also shown in Figure 3 and 4. Most of the global climate models projected an increase in precipitation in both the dry and wet seasons of Ethiopia (Adefris *et al*., 2013). Other studies with more detailed regional climate models, however, indicated that the expected precipitation change is uncertain (Schneider *et al*., 2008). On the other hand, the temperature will very likely continue to increase for the next few decades with the rate of change as observed by Brohan *et al*. (2006).

The projected increases in the inter-annual variability of precipitation in combination with the increasing temperature will likely leads to increase the occurrence of drought. Moreover, heavy rain and flood are also projected to increase as well (Brohan *et al*., 2006). Decreases in rainfall amount will be exacerbated by higher evaporation rate, which is associated with increasing temperature. Projections of temperature are more certain to occur other than those of precipitations and considerable regional variations will exist (Brohan *et al*., 2006).

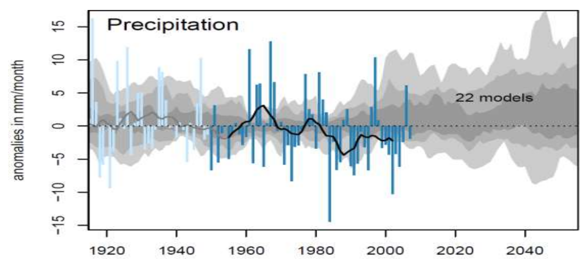

Figure 3. Observed and projected changes in precipitation in Ethiopia (Brohan et al., 2006)

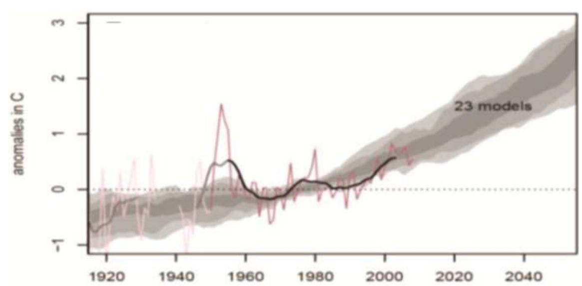

Figure 4. Observed and projected changes in temperature in Ethiopia (Schneider et al., 2018)

3. Causes of Climate Change and Ethiopia`s Contribution

The causes of climate change could be natural factors and/or human induced activities/anthropogenic factors. Human activities like burning of fossil fuels and agriculture together with widespread deforestation are emitting greenhouse gases including CO_2, nitrous oxide, chlorofluorocarbons (CFCs) and methane to the atmosphere, which absorb the thermal radiation emitted from the Earth's surface. The greenhouse gases are those gases in the atmosphere that absorb thermal radiation emitted by the Earth's surface, which have a blanketing effect upon it (Adefris *et al*., 2013).

The important greenhouse gases that are directly influenced by human activities are carbon dioxide, methane, nitrous oxide, the chlorofluorocarbons (CFCs) and ozone. Carbon dioxide is a good absorber of heat radiation coming from the Earth's surface, increased carbon dioxide acts like a blanket over the surface, keeping it warmer than it would otherwise be. The gas methane is also increasing because of different human activities, for instance mining and agriculture, are adding to the problem. Many scientists now believe that there is a direct link between this warming and emissions of greenhouse gases such as carbon dioxide (CO2), nitrogen oxides and methane. In addition to human factors, natural factors including volcanic eruptions affect global warming. Due to volcanic eruption, 25 million tons of carbon dioxide released to the atmosphere (IPCC, 2007).

The contribution of Ethiopia for global climate change is very low compared to other developed countries. According to Devereux (2006), the emission of greenhouse gases (GHG) in Ethiopia in 1994 was estimated to be 900 kg CO_2 equivalent per capita per year while USA emits about 23.7 tones CO_2 equivalent per capita per year in 1994. Ethiopia's GHG emissions are mainly sourced from agriculture, which contributes up to 80% of the total emission of the country. In addition, the energy sector (heating, cooking, and transport) contributes about 15% of the total emissions where about 95% of the energy is sourced from bio-masses, petroleum and electricity (Figure 5). Ethiopia's GHG emissions are closely linked to the basic needs of population of the country like food production and heating.

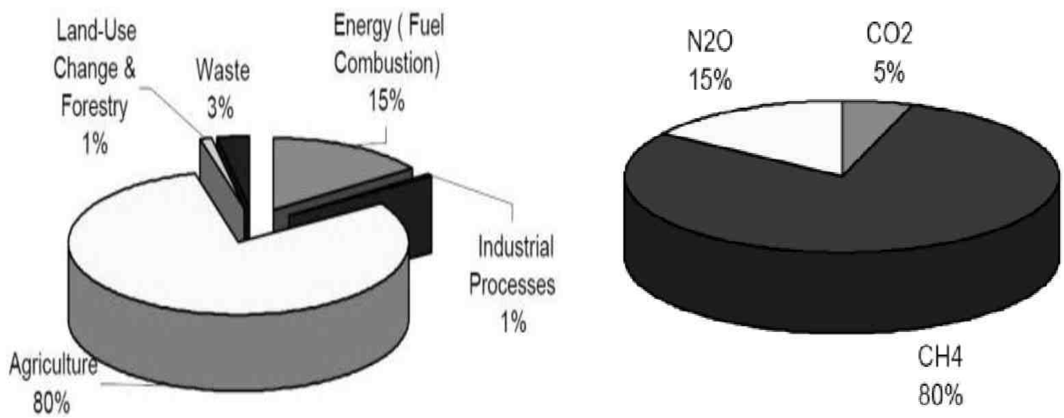

Figure 5. Total GHG emissions by sectors in Ethiopia and the relative contribution of individual greenhouse gases to climate change (NMSA, 2001)

4. Impacts of Climate Change on Crop Production of Ethiopia

4.1. Effects of climate change on agronomic activities

According to Adefris *et al*. (2013), crop production in Ethiopia is practiced during the rainy season as rain fed agriculture. Therefore, delay on the onset of rainfall hampers the regular land preparation activities and postpones the time of sowing or planting of crops. Drought also affects land preparation through either weakening or causing death of oxen that are used for tillage of croplands. Delay in onset and early cessation of rainfall forces the farmers to miss the optimum planting time of crops. As a result, farmers fail to plant long-season crops especially in semi-arid areas where the soils have mostly low water holding capacities. In this regard, Brohan *et al*. (2006) reported significant reduction of the growth and performance of long cycle crops of maize and sorghum due to poor performance of rain during the months of April and May.

4.2. Effects of climate change on opportunities to grow different crop types or varieties

Climate variability/change reduces opportunities of the farmers to grow different crop types or varieties in a given area. According to Yesuf *et al.* (2008), crops like fababean, lentil and wheat grown in the midlands are being replaced by sorghum, maize and haricot bean in response to declining and erratic rainfall distribution. Areas used for growing of chickpea, peas and long maturing sorghum varieties in Central Rift Valley are now growing medium or early maturing varieties of other crops because of early session of rainy season. Replacement of maize and sorghum over time by early maturing teff varieties as well as late planting of crops with lower total water consumption has been observed in most of the semi-arid regions of Ethiopia. Currently, maize and sorghum cultivars grown in Adama and Miesso areas are prone to the impact of water deficit, which results in the reduction of yields as indicated by Giorgis *et al.* (2006).

4.3. Effect of climate change on yields of crops

The most prominent impacts of climate change are reduction of crop yield. In severe cases, climate change may cause total failure of crop harvest. Irregular rainfall distribution affects the growth and development as well as the phenology of different crops. Moreover, occurrence of rainfall during the harvesting time may cause shattering of crop grains, pre-harvest seed germination and disturb harvesting operations. Due to the erratic rainfall distribution, up to 100% crop losses were recorded in various parts of West Arsi Zone of Oromia Region in different crop growing years (Adefris *et al*., 2013).

Based on the reports of Nelson *et al.* (2009), the yields of rice, wheat and maize have been reduced 15%, 34%, and 10%, respectively, due to the impacts of climate change in Sub-Saharan Africa. Similarly, the yield of maize has been reduced by 80% and 25% in Boricha and Metarobi lowlands, respectively, in southern part of Ethiopia because of shortage of rainfall during the months of March to May in 2004 growing season (Roach, 2005). Similar findings were also reported by Devereux (2006) who reported highly vulnerability of food production in semi-arid areas of Somali Region in Ethiopia.

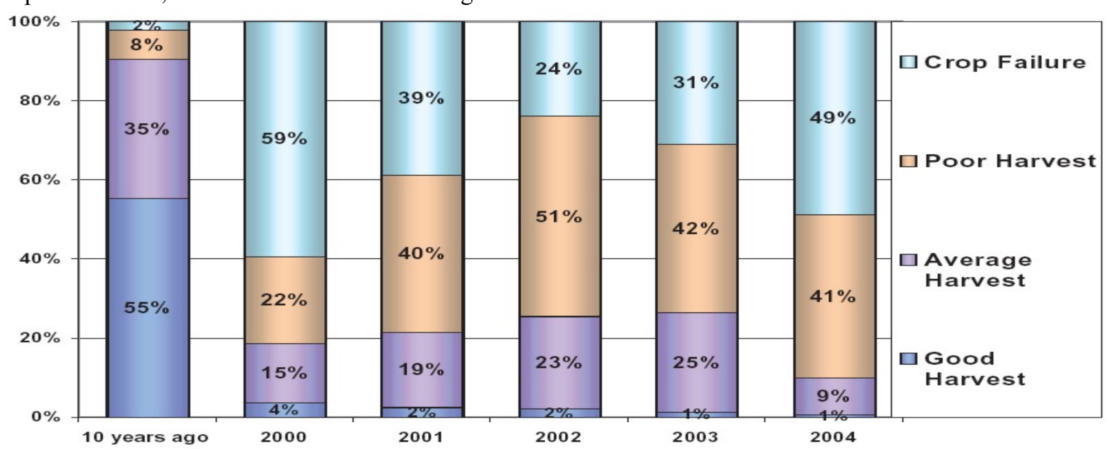

Figure 6. Crop harvest of Somalia Region in different years (1994–2004) (Devereux, 2006)

Generally, water availability is the most critical factor for sustaining crop productivity in rain fed agriculture as it greatly affects availability of soil water necessary for crop production and thus poses crop production risks. In this regard, Bewket (2009) has observed the relationships of rainfall distribution with yields of cereal crops in Amhara Region (Table 1).

The yield increment of teff was observed when the rainfall was increased from May up to August. However, the yield of teff was decreased due to the short rain. The yield increment of barley was observed during the rainy seasons including May, June, August and September. With regards to wheat, rainy seasons including May, July, August and September, maximizes wheat yield as compared to other rainy seasons. In these contexts, barley and wheat needs long rainy seasons. For maize, rainy seasons including May, July and August are the critical periods for maize production. With regard to sorghum, May and June are the critical periods for sorghum production. In addition, sorghum needs short rainy seasons as compared to other crops. According to Bewket (2009), the raining during the months of May, July and August are the most appropriate rainy seasons for millet production. Generally, different crops need different rainy seasons and their production depends on their respective rainy seasons (Bewket, 2009).

Similarly, Yesuf *et al.* (2008) reported negative anomalies in the production of teff, maize, sorghum and millet, which have been contributed to the low-average total cereal production in the region. The variability of water has been shown severe effects of sorghum, whose cultivation is dominated in the semi-arid and arid parts of the country which is prone to rainfall variability.

Table 1. Relationships between yields of cereal crops with monthly, seasonal and annual rainfall distribution in Amhara Region (Bewket, 2009)

Months	Teff	Barley	Wheat	Maize	Sorghum	Millet
May	0.137	0.444	0.506*	0.309	0.492	0.503
June	0.189	0.421	0.414	0.188	0.503	0.176
July	0.199	0.049	0.612*	0.345	0.079	0.224
August	0.623*	0.273	0.564*	0.349	0.260	0.236
September	0.493	0.348	0.733**	0.149	0.212	0.127
Belg (short rain)	-0.001	-0.24	-0.17	0.19	0.57	0.21
Kiremt (long rain)	0.47	0.43	0.80***	0.23	0.10	-0.005
Annual	0.26	- 0.35	-0.17	0.33	0.37	0.23

* = $p < 0.1$; ** = $p < 0.05$; *** = $p < 0.01$

5. Adaptation and Mitigation Strategies of Climate Change

5.1 Adaptation strategies

Adaptation is processes through which the societies make themselves better able to cope up with an uncertain future. Adaptation strategies entail taking the right measures to reduce the negative effects of climate change by making the appropriate adjustments and changes (UNFCCC, 2007). Accordingly, about 58% of the farmers in the Nile basin of Ethiopia are implementing some traditional adaptation measures to reduce the impacts of climate change that indicates the awareness of the farmers to change climates (Adefris *et al.*, 2013). They are practicing different adaptation strategies including timing of various soil preparation operations and adjustments of frequency of tillage, selection of crop types based on soil moisture and slope, choose of the most suitable crop varieties and crop rotations and planting density, use of intercropping and other technologies to increase the efficiency of water use (Molla, 2009).

Moreover, the farmers have also introduced traditional irrigation and water harvesting schemes to cope with water stress during the growing period. Suggested adaptation strategies that can be implemented to improve crop production and productivity for possible climate change scenarios with the corresponding challenges/impacts are summarized in Table 2.

Table 2. Farm level climate change adaptation strategies for crop production in Ethiopia

Climate change related scenario	Challenge/impact	Adaptation options	Reference
Lack of seasonal rainfall (less than 250 mm)	Water requirements of crops cannot meet at any stage of growth, therefore crop production under rain-fed farming is impossible	Installation of irrigation scheme	Molla, 2009
Irreversible shift on onset of rainfall from early to late	Planting of long season varieties of crops cannot be possible	Planting of medium and or short season cultivars to fit the modified onset of rainfall	Bewket, 2009
Early cessation of rainfall	Length of the growing season of crops will be shortened, thus yield of crops will be reduced (e.g. shortened grain filling period, shriveled grain)	Implementation of water harvesting technologies for supplemental irrigation and increasing water use efficiency by using modern irrigation methods and mulching to conserve the available water. Implementing weather-based insurance scheme for climate risk management	Yesuf *et al*., 2008
Soil water deficit as evaporative demand exceeds rainfall amounts	Crop production is possible, but rainfall is insufficient to meet crop water requirement	Implementing water harvesting technologies for supplemental irrigation at critical growth stages of crops and increasing water use efficiency by using modern irrigation methods. Mulching to conserve the available water and soil amendments to improve water holding capacity. Increasing water productivity (grain yield mm^{-1}) through cultivar choice and improving soil water management practices Implementing weather-based insurance scheme	Devereux, 2006
Unpredictable onset of rainfall extreme high rainfall	Difficult to practice the recommended agronomic operations (tillage, date of sowing, fertilizer use, etc)	Use of seasonal rainfall forecast information from National Meteorology Agency for early warning and use of the information from Bureau of Agriculture; implementation of weather-based insurance scheme	UNFCCC, 2007

Erratic distribution and extended dry spells after onset of rainfall	Reduction of crop yields or total crop failure due to shortage of moisture at critical stages of growth of crops	Implementing water harvesting technologies for supplemental irrigation at critical growth stages of crops and increasing water use efficiency by using modern irrigation methods. Mulching to conserve the available water and soil amendments to improve water holding capacity. Increasing water productivity (grain yield mm^{-1}) through cultivar choice and improving soil water management practices	Nelson *et al*., 2009
Torrential storms over a short time (days)	Rainfall exceeds infiltration capacity of the soil as result erosion, occurrence of soil born diseases, reduction of crop establishment and development	Establishment of drainage channels for safe disposal of excess water; development of varieties resistance to soil born diseases through breeding; harvesting excess water to be used during the times of water deficit	Deressa, 2006
Heat load	Premature switchover of the crops from vegetative to reproductive stage, occurrence of heat	Development of varieties that tolerate heat stress through breeding; irrigation to component evapo-transpiration losses	Giorgis *et al*., 2006

As Ethiopian crop production is highly dependent on rain fed, even short-term fluctuation in weather patterns significantly impacts the income of smallholder farmers. Loss of harvest could lead to loss of life. Within the current economic and technological constraints, farmers are usually barely adjusting to short-term climatic anomalies. In order to help the farming communities to cope better with climate variability and potential effects of long-term climate changes, the government of Ethiopia is trying to implement adaptation and mitigation strategies of climate changes through rigorous natural conservation practices (Bewket, 2009). Among the mitigation strategies practiced in the country, promotion of agro-forestry and afforestation, use of renewable energy sources, development of land use plan, promotion of conservation agriculture and use of organic fertilizer are the most important once (Molla, 2009).

Moreover, the government of Ethiopia is trying to improve the production and productivity of agriculture through polices of Agricultural Development Led Industrialization (ALDI), Growth, and Transformation Plan (GTP). Generation and implementation of improved crop production technologies have been done through these policies to raise the productivity of the agriculture sector and thus being self-sufficient in food production (World Bank, 2011). The Early Warning and Response Department (EWRD) have been also established under the Ministry of Agriculture and Rural Development (MoARD) with the aim of managing disasters. The EWRD; therefore, has developed a Disaster Risk Management Policies that attempt to directly reduce the impact of disasters (Adefris *et al*., 2013). However, more effort has to be done in developing and strengthening the institutional capacity of EWRD towards mitigation of the impacts of climate change.

Although there is availability of polices and strategies for adaptation and mitigation of climate changes, the program is constrained by various problems including lack of information about future climate change scenario, traditional farming practices, shortage of fund, poor irrigation infrastructures, lack of researches and poor extension services (Yesuf *et al*., 2008). Therefore, intensified investment in researches and extension services should be promoted that should be also linked with increasing farmer`s access to appropriate technologies, credit facilities and climate information as well as marketing and distribution networks (EARO, 2000). To this end, coordinated approach among governmental institutions and NGO is very important. Regular information exchanges and consultations would have to be organized between the respective stakeholders including National Metrology Agency, Ministry of Agriculture, extension services, NARS, and farmer`s unions and associations to monitor the current and future climate and environmental conditions of the country so as to establish an effective early warning system (Adefris *et al*., 2013).

5.2 Mitigation strategies

Currently, various mitigation options have been practiced in Ethiopia. Some of these include, promoting agro-forestry and afforestation, promoting conservation agriculture and organic soil fertilization, integrated waste management, improving the lad use, promoting the use of renewable energy, improving/promoting energy efficiency and conservation, promoting the use of fuels with low carbon content (fuel switching) (Molla, 2009).

Ethiopian farming is based on smallholder farmers and highly dependent on rain fed agriculture. Short-term fluctuations in weather patterns and, therefore, have significant impacts on farm income. A loss of harvest could mean loss of life. Within the current economic and technological constraints, usually farmers barely adjust to short term climatic anomalies. In order to help households and the farming communities better to cope with climate variability and potential long-term climate changes, government policies must address stagnation and under-investment in the agriculture sector, and the rapidly growing population has increased the ability of farmers to deal with shocks (Bewket, 2009).

The Economic Development Policy of Ethiopia has given the highest priority to agriculture under the aegis of an agriculture-led industrial development. Agriculture is already built into the Agricultural Development Led Industrialization (ALDI) and the Growth and Transformation Plan (GTP) and is the foundation for many of the other activities. In an effort to raise productivity of the agriculture sector and to be self-sufficient in food production, the government is focusing on generating and delivering technologies that will improve agricultural production (World Bank, 2011).

Most of the policies, strategies and development plans do not explicitly reflect climate change, although many of the proposed activities are directly aimed at reducing the impacts of drought. However, many of these programmes and policies encourage higher agricultural productivity through intensification. The Early Warning and Response Department (EWRD) have been established with a new institutional mission under the MoARD. The EWRD has already developed a Disaster Risk Management Policy for Ethiopia that attempts directly to reduce the impact of disasters (Adefris *et al*., 2013).

The availability of such policies and strategies is useful to develop the agriculture sector and improve disaster management. However, more effort is required in developing and strengthening of institutional capacity for mitigating the impacts of climate change. In this regard, intensifying investment in research and extension services to generate relevant technology and enhancing their immediate impact should be promoted. This should be linked with increased farmer access to appropriate technologies, climate information, measures to improve the marketing and distribution networks, and access to credit facilities (EARO, 2000).

While climate change will affect all sectors, it requires a coordinated approach among government institutions and NGO. Activities carried out by one ministry, agency or organization may contradict directly or indirectly with another and nullify one's effort unknowingly. Regular information exchanges and consultations would have to be organized between the weather forecasting stations, NARS, the agricultural extension service and farmer unions and associations. The NMA, Ministry of Agriculture, NGOs, and the NARS should effectively monitor current climate and environmental conditions in the country and establish an effective early warning system (Adefris *et al*., 2013).

6. Conclusion and Recommendations

Climate changes and their impacts in changing of weather patterns are already happening in Ethiopia while Ethiopia`s contribution to climate change is very limited. The negative impacts of climate change in the country are expressed in reduction of agricultural productivity and food insecurity, which will be exacerbated in the future. The impacts of the current climate variability on crop production have being clearly evident through the change in planting time of crops, length of growing season, crop types or cultivars grown in a given area, reduction of soil fertility and thus reduction of production and productivity of crops where food production is highly correlated with the rainfall patterns. Crop failure is also frequent during bad seasons.

Water harvesting for supplemental irrigation, improving water use efficiency by implementing modern irrigation methods and application of mulching materials and proper management of soil water as well as selection of appropriate crop types or cultivars and implementation of proper agronomic practices can be used as climate change adaptation strategies for crop production in Ethiopia. Moreover, climate change can be mitigated by rigorous natural resource management strategies including afforestation, promotion of agro-forestry, and use of renewable energy sources and development of land use plan.

Since, implementation of climate change adaptation and mitigation strategies are complex the following issues are recommended to improve production and productivity of crops in Ethiopia:

- Capitalize on the existing development policies and programmers and design short- and long-term action plans to implement adaptation and mitigation strategies;
- Increase research and extension services to generate data and technologies appropriate to adaptation strategies within the different agro-ecological zones;
- Improve the linkage and capacity of respective stakeholders including governmental organization and NGOs;
- Improve awareness and understanding of local communities about the relationship between climate change and crop production; and
- Improve the system of data collection, analysis and dissemination network to evaluate vulnerability to climate change and formulate decision support.

Conflict of Interest

The authors declare the absence of conflict of interest in publication of the manuscript.

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Effect of Cassava Products Consumption on Food Security of Farming Households in Kwara State, Nigeria

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Received: June 4, 2019 Accepted: July 23, 2019

Abstract: *Cassava is widely known as a food security crop and about 80% of Nigerians consume cassava products, at least once a day. Nevertheless, food insecurity is still a critical issue among farming households. Consequently, we evaluated the consumption frequency of cassava products and assessed the effect of consumption of cassava products on food security among farming households. Random sampling technique was used to pick 200 farming households for this study. The analytical tools are descriptive statistic, food security index and binary logistic regression. The study revealed that the commonly consumed cassava products by the respondents were Garri, cassava tuber and Fufu. Among cassava based foods, Garri was the most frequently consumed staple. Furthermore, 28% and 72% of the respondents were food secured and in-secured, respectively. The regression analysis indicated that household size, household income, quantity of Garri consumed, quantity of Fufu consumed, quantity of other cassava products consumed and access to credit facilities were the critical factors explaining food security. In addition, eating foods that are less preferred, eating more of Garri and Fufu were the most effectual coping strategies adopted by respondents in cushioning the effects of food insecurity. Government should encourage production of cassava and other leguminous crops by given incentives such as soft loans to farmers. Farmers should also be encouraged to consume cassava products with other protein rich foods. In addition, processors should produce more of Fufu, Lafun and Garri products. Moreover, policies and strategies that raise household income and lowers family size should be enhanced to reduce food insecurity.*

Keywords: Cassava products, Farming households, Food security, Kwara state

1. Introduction

Food is essential to life. It occupies a large part of typical Nigerian household expenses. Thus, food security is critical to any country of the world. Food security occurs when all people, at all times, have enough physical, civic and financial means to secure and nourish food that satisfies their dietary needs and food choices for an energetic and beneficial life (FAO, 2005). For food security to exist at the national, regional and local levels, food must be available, accessible and properly utilized. Food availability means that enough, safe and nutritious food is either domestically produced or imported from the international market. Food availability does not ensure food accessibility. For food to be accessible, individuals or families must have sufficient purchasing power or ability to acquire quality food at all times while utilization demands sufficient quality and quantity of food intake (Omonona *et al*., 2007). These elements of availability, accessibility and utilization in a larger context, embraces the supply, demand and adequacy of food at all times. Food insecurity on the other hand occurs when there is real inapproachability of food, poor social and economic access to enough food and/or poor food conversion. Food insecurity if left untacked, could cause increased vulnerability to diseases and parasites, reduced strength for tasks requiring physical effort, reduction of the benefit from schooling and training programs and general lack of vigor, alertness and vitality. The outcomes of these is a reduction in the productivity of people in the short and long terms, sacrifice in output and income, and increasing difficulty for families and nations to escape the vicious cycle of poverty. Attempt to ensure food security can, therefore, be seen as an investment in human capital that will make for a more productive society. A population that is properly fed, healthy, alert and active contributes more productively to economic development than one which is physically and mentally challenged by inadequate diet and poor health (World Bank, 1986).

Food insecurity is still a critical issue among farming households in Nigeria (Salau *et al.,* 2018). The food insecurity situation in Nigeria is aggravated because food demand has grown faster than food production (Idrisa *et al*., 2008), the CBN (2001) corroborates this when it maintained that the rate of increased food production of 2.5% per annum does not measure up with the annual population growth of 2.8%. In addition, poor processing techniques and low productivity of the farmers under uncertain weather conditions and fluctuating market prices worsened food security situation of households (Oriola, 2009). Furthermore, post-harvest losses and low quality products make farmers vulnerable to food insecurity (Langat *et al.,* 2010).

Cassava (*Manihot spp.*) a food security crop, can play significant role in reducing this devastating effect of food insecurity among farming households. About 80% of Nigerians consume cassava products, at least once a day. Cassava derives its importance from the fact that it is starchy, a cheap source of carbohydrate, more so, its roots are a valuable source of cheap calories especially in developing countries where calories deficiency and malnutrition are well pronounced. In addition, cassava is mostly cherished due to the following characteristics: it is easily propagated by stem cuttings and can resists drought and diseases. It is within the reach of rural people, high yielding, can adapts to poor soils, can be cultivated at any time of the year and can be processed into different forms (IITA, 2004). More importantly, cassava gives the highest profits in monetary terms to naira invested (Ezike *et al.,* 2011). Moreover, most households grow cassava as their main stable food because it requires less seasonal labor.

Cassava became well known in Nigeria following the pronouncement of presidential initiative on cassava in 2002. Through food diversification program, there has been keen interest from the government to find alternative sources of carbohydrates, especially to enhance food security. Presently, attention is turning to traditional root crops, especially cassava, because of its capacity to yield under marginal soil conditions and its tolerance to drought. Consequently, cassava became a substantial part of the diet of more than 70 million Nigerians (FAO, 2003). Apart from serving as food for human consumption, it has numerous industrial uses like chips, flour, starch and the leaves which have a high export potential. Despite the important roles cassava plays, it does not provide a balance diet and thus its consistent consumption as staple food without protein or other classes of food may leads to malnutrition. The farming households who produce bulk of cassava have low disposable income to achieve a food security benchmark of daily availability of 2260Kcal of energy and 65g of protein per capita. Numerous studies (Babatunde *et al.* 2007; Omonona, 2007; Amaza *et al.,* 2008; Ahmed, 2016; Salau *et al.,* 2018) have been done on factors influencing food security of households. However, none of these studies have considered the effect of the consumption of cassava products (Garri, Fufu, and Lafun) on households' food security. Thus, this study evaluated the consumption frequency of cassava products and examined the effect of the consumption of cassava products on food security of farming households in Kwara State, Nigeria.

2. Conceptual Framework

2.1. Concept of Food Security

Food security in a broad sense has to do with having at all times an adequate level of food and food products to meet increasing consumption demand to mitigate fluctuation in output and price (Idrisa *et al.,* 2008). According to FAO (1996) food security is a situation when all people at all time have physical and economic access to sufficient, safe and nutritious food for a healthy and active life. Ladele and Ayoola (1997), reported food security as a function of food production level, that is, high level of food production is equals to food security. According to Von Braun et al. (1992) and Omonoma and Agoi (2007), there are four major elements of food security; food availability, food access, food utilization, and not losing the excess. However, to Oriola (2009), food security entails producing food that will go round every citizen both in quality and quantity. To achieve this, agricultural production needs to be enhanced with adequate knowledge of the environment, climatic condition, the market and its operation, and be aware of price and price mechanism, good transportation system, storage, fashion modality to check glut and be well prepared in case of disasters.

Food insecurity is the opposite of this, it is the lack of access to sufficient quality and quantity of save nutrition food for an active and healthy life; the inability of households or individuals to meet the required consumption level in the face of fluctuating production, price, and income (Maharjan and Chhetri, 2006). According to Gillespie and Haddad (2001), food insecurity boils down to inability of households to have reliable access to food in sufficient quantity and quality to enjoy active and healthy life. Food importation as a result of insufficiency has continued to be on the rise in Nigeria a country which according to Edokpa and Okafor (2009) is the highest food producer in sub-Sahara Africa. Food wastage has also been indicated as a bane of food security in Nigeria. The country experienced food wastage of 0.81 million metric tons between 1995 and 2000 and this would reduce greatly if storage facilities are in place. Export of staple food has also been indicted as a cause of food insecurity, the export of staple food crops should be de-emphasized (Igberaese and Okojie-Okoedo, 2010).

3. Materials and Methods

3.1 Study Area

The study area is Kwara state. The latitude and longitude of the state are: 8º and 10º north and 3º and 6º east, respectively. The state has an area of 35,705 Sq kilometers with a population 193,392,500 people (NPC 2016). To the west, Kwara state shares an international boundary with the Republic of Benin and to the north an interstate boundaries with Niger state. It also shares boundaries with Oyo, Osun and Kogi states to the southwest, southeast and east respectively (Figure 1).

Figure 1. Map of Kwara state, Nigeria
Source: Adapted from Ibiremo *et al,* (2010)

The climate consists of both wet and dry seasons each lasting for nearly six months. The raining season starts in April and end in October while the dry season commences in November and stops in March. Temperatures range from 33^0C to 34^0C, with the total annual rainfall of about 1318mm. Agriculture remains the principal occupation of the people. The commonly grown crops are: cassava, millet, maize, okra, sorghum, cowpea, yam, sweet potatoes, and palm tree. The state has about 1,258 rural communities. Based on ecological characteristics, cultural practices and project's administrative convenience, the state is grouped into four zones by Kwara state Agricultural Development Project

(KWADP). These are: Zone A: Baruteen and Kaima Local Government Areas (LGAs); Zone B: Edu and Patigi LGAs; Zone C: Asa, Ilorin East, Ilorin South, Ilorin West and Moro LGAs and Zone D: Ekiti, Ifelodun, Irepodun, Offa, Oyun, Isin and Oke-Ero LGAs (KWADPs, 2010).

3.2. Method of Data Collection and Sampling

Primary data was engaged for this study. Data were collected using structured questionnaires. A three-stage sampling technique was used to pick respondents for this study. The first stage involved purposive selection of zone D. This zone is the largest cassava producing zone in the state. The second stage involved random selection of four Local Government Areas (LGAs) out of the 8 LGAs in the zone. In the third stage, a random selection of 25 farming households from each selected LGA to make up a sample size of 200 respondents was done.

3.3. Analytical Techniques

The tools of analysis were: descriptive statistics, Likert scale, food security index and binary logistic regression. The socioeconomic characteristics were explained using descriptive statistics. A food security index was used to classify households into food secure or food insecure depending on which side of the line they belong.

The index is given as:

$$Yi = \frac{Xi}{M}$$

Food security index (Yi) is the ratio of daily per calorie intake X*i* and recommended per calorie daily intake M.

The household calorie intake was obtained through the household consumption and expenditure data. The quantity food consumed by the household in seven days was converted into its calorie content. This was further converted into per capita calorie by dividing the estimated total household calorie intake by the adjusted household size in adult equivalent. Moreover, the per capita calorie intake was converted into daily per capita intake by dividing for seven days. The calorie requirement based on recommended per calorie daily intake M of 2260Kcal per adult equivalent was used (Babatunde *et al.,* 2007).

If the food security index (Y*i)* is equal or greater than 1 *(*Y*i* ≥1), the household is said to be food secure. On the other hand, if the food security index (Y*i)* is greater than 0, but less than 1(Y*i*< 1), the household is food insecure.

Binary logistic regression was used to identify the drivers of food security among farming households. The model is given as:

$$Yi = a_o + a_1N_1 + m_aN_2 + \ldots + a_kN_k + e$$

Where

Yi= the binary food security status (food secure household takes the value of 1 and 0 if otherwise.

a_o= Constant

N = independent variables

e = error term

The independent variables are:

N_1 = Sex of the respondent (D=1 for male; D=0 for female)

N_2 = Age of household head (years)

N_3 = Household size (number)

N_4 = Education status (years of schooling)

N_5 = Monthly income in Naira

N_6 = Quantity of Garri consumed in kg

N_7 = Quantity of Fufu consumed in kg

N_8 = Other cassava products consumed (kg)

N_9 = Access to credit (1 for Access to credit and 0 if otherwise)

A-three point Likert-scale was used to identify frequency of cassava products. The response options and values assigned were as follows:

Very often = 3;

Often = 2; and

Not often = 1.

These values were added and divided by 3 to obtain 2.0, which was regarded as the average. Cassava products that have mean scores greater than 2.0 will be regarded as frequently consumed. Similarly, a-three point Likert-scale was used to identify the effective coping strategies employed by households in cushioning the effect of food insecurity, the response options and values assigned were as follows:

Very effective = 3;

Effective = 2; and

Not effective = 1.

These values were added and divided by 3 to obtain 2.0, which was regarded as the mean score. Strategies that have mean scores greater and lower than 2.0 will be regarded as effective and ineffective, respectively.

4. Results and Discussion

4.1. Socio-economic Characteristics of Respondents

Most (75.5%) of the respondents were males (Table 1). Based on traditions, the male respondents usually have more access to farmland when compared with their female counterparts. The mean age of the respondents was 48.5 years. Age is a critical variable, which can influence the capacity and alacrity with which the head provides foods for the household. An old respondent may have bigger household size and may not have the vigor needed to work for the maintenance and nourishment of the household

Table 1. Socio-economic characteristics of respondents

Variable	Frequency	Percentage	Mean
Age			
1- 30	45	22.5	
31-60	90	45.0	48.5
61-90	65	32.5	
Gender			
Male	151	75.5	
Female	49	24.5	
Years of education			
1- 5	65	32.5	
6-10	75	37.5	6.8
11-15	50	25.0	
16-20	10	5.0	
Marital status			
Single	28	14.0	
Married	153	76.5	
Divorce	16	8.0	
Separated	3	1.5	
Household size			
1-5	55	27.5	
6-10	79	39.5	8.7
11-15	48	24.0	
16-20	18	9.0	
Main source of income			
Agriculture	78	39.0	
Salary	74	37.0	
Trading	48	24.0	
Access to credits			
Yes	58	29.0	
No	142	71.0	
Monthly income			
50,000 - 100,000	139	69.5	
101,000-150,000	50	25.0	67,700
151,000-200,000	11	5.5	
Farm size (has)			
1 – 5	145	72.5	
6 -10	38	19.0	4.8
11-15	17	8.5	

Source: field survey, 2019

Twenty-nine percent of the household heads had access to credit facilities. Access to credit may affect the type of food eaten and expenses of households. The average years of education were seven years. Education enables the respondents to take good decisions, which may likely enhance their food security status (Babatunde *et al.,* 2007). The respondents operated at a subsistence level with a mean farm size of 4.8 hectares. The size of farmland cultivated may affect output production and food security of the respondents (Akinsanmi and Doppler, 2005). In addition, the study revealed that the mean monthly income was ₦67, 700. The average household size was nine, and their polygamous way of life probably accounted for the large household size recorded in the study area.

4.2. Frequency of Consumption Cassava Products

Table 2 revealed that Garri with a mean score of 2.80 was ranked first. Hence, garri is the most frequently consumed cassava products. Garri is usually obtained by grinding the tuber and squeezing out the starchy component. The remains is then fermented and dried.

Table 2. Cassava products and their frequency of consumption

Cassava Products	VO Freq (%)	O Freq (%)	LO Freq (%)	MS	Ranking
Lafun	39 (16.3)	171 (71.3)	30 (12.5)	2.04	4th
Garri	200(83.3)	33(13.8)	7(2.9)	2.80*	1st
Fufu	127 (52.9)	98 (40.8)	15 (6.3)	2.47*	3rd
Starch	0 (0.0)	52 (26.0)	148 (74.0)	1.01	5th
Kabioka	0 (0.0)	3 (16.5)	167 (83.5)	1.01	5th
Cassava tubers	161 (67.1)	58 (24.2)	21 (8.8)	2.58*	2nd

*Mostly consumed, VO = Very Often, O=Often, LO=Less Often
Source: Field Survey (2019)

Garri is slightly followed by cassava tubers with a mean score of 2.58. Others are Fufu (mean score 2.47), Lafun (mean score 2.40), and starch (mean score 1.01). From the foregoing, Garri, Cassava tuber Fufu, and Lafun were ranked first, second and third respectively. This suggests that they are the mostly consumed cassava products by the respondents in the study area.

4.3. Food Security Status of Farming Households

Table 3, indicated that 72.0% and 28.0% of the households were food secure and insecure respectively. These findings agree with that of Ifeoma and Agwu (2014), who found out that 74.2% of the households were food secure while 25.8% were food insecure in their study on an assessment of food security situation among farming households in rural areas of Kano State, Nigeria.

Table 3. Food security status of households

Variables	Status		
	Food secure *	Food insecure	All
Percentage of households	28.0	72.0	100
Number of households	56	144	200

*Recommended for being food secure 2260Kilo calorie per day (Babatunde *et al.,* 2007)
Source: Field Survey, 2019

4.4 Determinants of Food Security

The logistic regression revealed that gender, educational status, household size, household income, access to credit, quantity of Garri, Fufu and other cassava products consumed are important determinants of food security (Table 4).

Table 4. Factors influencing food security

Determinants of Food Security	Coefficient	Std. Error	Sig.	t-value
Sex	0.290	.641	.444	0.186
Age	.154	.221	.485	0.696
Household size	-.287	.136	.035**	2.110
Years of education	.469	.262	.074***	1.790
Household income	2.492	.378	.000*	6.593
Garri	.373	.046	.081***	8.109
Fufu	-.011	.006	.075***	1.833
Other cassava products	-.739	.112	.049**	6.598
Access to credit	-.528	.249	.040**	2.120
Constant	3.463	1.616	.032	2.143

$R^2 = 51.32$

Source: Field Survey, 2019 *, **, *** significant at 10%, 5% and 1% levels respectively

The coefficient of household size was negative and significance at 5% level of probability. This implies that as household size decreases, the food security status increases. The coefficient of educational status was found to be positive and significant at 1% level of probability. The positive relationship between educational level of household heads and food security implies that households with an educated household head are more likely to be food secure than those with an uneducated household head. Also, the higher the number of years the household head spends in school, the more the probability of the household being food secures. This agrees with the findings of Babatunde *et al.* (2007) and Amaza *et al.* (2008). The coefficient of total income of the family was positive and significant at 10% level of probability. This implies that as total income of the family increases, the food security status is more likely to increase. The quantity of garri consumed is positive and significant at 1%. This implies that the more the quantity of garri consumed by the household, the more likely the household is food secure. Interestingly, the coefficient of fufu and other cassava products are negative and significant at 1% and 5% level of probabilities respectively. This suggests that the more the household consumes fufu and other cassava products, the more the household is food in secure. This could probably due to the fact that consumption of fufu and other cassava products does not provide a balance diet and may lead to malnutrition. Access to credit facilities is negative but important at 5% level. The negative sign suggests that probably the credit facilities were not used for the intended purposes. According to Babatunde *et al.* (2007), farmers' access to credit facilities is a crucial factor in determining the food security status of an individual as it had a significant coefficient at 5% in their study on socio-economic characteristics and food security status of farming households in Kwara State, North-Central Nigeria. They noted that farming households with good access to credit facilities have greater probability of being food secure than those without credit facilities.

4.6. Coping Mechanism

The most effective coping strategies employed by the households in cushioning the effect of food insecurity are eating foods that are less preferred (mean score = 2.58), eating more of Garri (mean score = 2.37), eating more of Lafun (mean score = 2.24), eating more of starch (mean score = 1.07), eating more of Fufu (mean score = 2.30), consuming more of cassava tubers (mean score = 1.07), borrowing food from friends and relative (mean score = 1.50) and borrowing money to buy foods (mean score = 1.43) (Table 5).

Table 5. Coping mechanisms employed by the households

Copping strategies	Very Effective	Effective	Less Effective	MS	Ranking
Eating less preferred foods	121 (60.5)	58 (29.0)	21 (10.5)	2.58*	1st
Eating more of Garri	71 (35.5)	107 (53.5)	22 (11.0)	2.37*	2nd
Eating more of Lafun	98 (40.8)	102 (42.5)	40 (16.7)	2.24*	4th
Eating more of Starch	0 (0.0)	98 (49.0)	102 (51.0)	1.07	7th
Eating more of Fufu	68 (34.0)	110 (55.0)	22 (11.0)	2.30*	3rd
Eating more of cassava tubers	3 (1.5)	76 (38.0)	121 (60.5)	1.07	7th
Borrowing food from friends	23 (11.5)	98 (49.0)	79 (39.5)	1.50	5th
Borrowing money to buy foods	15 (7.5)	94 (47.0)	91 (45.5)	1.43	6th

Source: Field Survey, 2019 *effective copping strategies

Using the mean scores above, eating food that are less preferred, eating more of Garri, Fufu and Lafun are the most effective coping strategies used by the households in reducing the effect of food insecurity and are ranked first, second, third and fourth respectively.

5. Conclusion and Recommendations

This study assessed the effect of the consumption of cassava products on food security of households in Kwara state, Nigeria. The study revealed that most (75.5%) of the respondents were males with an average age of 48.5 years. Cassava can be processed into different forms but is mostly consumed in the forms of Garri, Fufu and Cassava tubers**.** The food security index revealed that 28% and 72% of the households were food secure and food insecure respectively. Furthermore, age of the respondents, family size, income, access to credit, quantity of Garri, Fufu and other cassava products consumed were the critical factors influencing food security among the respondents. Eating less preferred foods, eating more of Fufu, Lafun and Garri products are the most important coping strategies adopted by the respondents to curb the effect of food insecurity. The government should encourage cassava production by given necessary incentives such as soft loans to farmers. Advocacy on the need to consume cassava products with other protein rich foods should be enhanced. Moreover, the processors should produce more of Fufu, Lafun and Garri products. Policies and strategies that raises household income as well as lowers family size should be enthusiastically pursued to reduce food insecurity in the area.

Conflicts of Interest

The authors declare no conflicts of interest.

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Impact of the Invasive Water Hyacinth (*Eichhornia crassipes*) on Socio-Economic Attributes: A Review

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Received: February 8, 2019 Accepted: October 7, 2019

Abstract: *Water hyacinth is a free-floating, stoloniferous and perennial herb. It is native to South America and profoundly invaded the tropical and subtropical regions. It is recognized as one of the worst weeds due to its rapid proliferation rate, ecological adaptability and detrimental effects on the environment, human health and economic development. It poses serious socio-economic and environmental problems including the reduction of water quality, hindrance to water transport and recreation, hampering agriculture and fisheries and affect hydropower and water supply system. In an attempt to control the weed, deferent management strategies such as physical, chemical, biological and integrated methods had been employed in several countries. As a result, the manual removal method was used in South Africa, Nseleni River; Zimbabwe, Lake Mutirikwi; Ethiopia,Wonji-Shewa Sugar Factory and Lake Tana; and Uganda, Owen fall hydropower in Jinja at Lake Victoria. The chemical control method was practiced in Zimbabwe of Lake Chivero and in experimental site using 2-4-D , acetic acid and glyphosate; South-west Nigeria of Ere fishing channel and South Africa of larger dams and river systems by using glyphosate. The biological control was practiced in Zimbabwe of Lake Chivero through a combination of weevil and fungi; and Ethiopia, trying to control the weed using Neochetina bruchi and fungi at Rift Valley, Wonji-Shewa Sugar Factory and in a greenhouse at experimental level at Bahir Dar University. Integrated management options and awareness creation in all aspects of the weed is recommended to reduce the negative imacts of the weed.*

Keywords: Chemical control, invasive aquatic weed, reduction of water quality

1. Introduction

Water hyacinth (*Eichhornia crassipes* Mart. Solms*)*, is one of the world's worst perennial aquatic herb, which belongs to the *Pontederiaceae* family (Gichuki *et al.*, 2012). It has been identified by the International Union for Conservation of Nature (IUCN) as one of the 100 most aggressive invasive species (Téllez *et al.*, 2008) and recognized as one of the top 10 worst weeds in the world (Shanab *et al.*, 2010; Gichuki *et al.*, 2012; Patel, 2012). Its rapid growth rate and high adaptability to extreme conditions contribute to its high degree of invasion (Hill *et al.*, 2011). Despite the fact that water hyacinth is native to the South American ecosystems, it is widely distributed to more than 50 tropical and sub-tropical countries over five continents (Bartodziej and Weymouth, 1995; Brendonck *et al.*, 2003; Jimenez and Balandra, 2007; Lu *et al.*, 2007). The weed originated from the Amazon Basin and has disseminated very quickly to many tropical and subtropical countries of Latin America, the Caribbean, Africa, Southeast Asia and the Pacific (Julien, 2000). Its improper use as waste water management and as an ornamental plant has tremendously increased its distribution worldwide (Villamagna and Murphy, 2010). The first introduction to the African continent was made in Egypt in the late 1880s (Navarro and Phiri, 2000). In Ethiopia, water hyacinth was officially reported in 1965 in Koka Lake and the Awash River (Yirefu *et al.*, 2007; Ayalew *et al.*, 2012) and infestation of Lake Tana was officially recognized in 2011(Ayalew *et al.*, 2012). Currently, water hyacinth infestation in Ethiopia has been manifested on a large scale in many water bodies of the country. The introduction and rapid spread of this weed in the Awash River Basin in *Koka* reservoir, Blue Nile River Basin in Lake Tana, and the head of Blue Nile River, Baro-Akobo River Basin in Sobate, Baro, Gillo and Pibor Rivers and Rift Valley Basins in Lake Ellen, Lake Abaya and Lake Elltoke, had created serious problems on the aquatic resources and the use of the water resources (Rezene, 2005; Taye *et al.*, 2009; Yirefu , 2017). At present, it is one of the invasive alien plants in the country (Rezene, 2005).

The success of this invasive alien species is largely due to its reproductive output. It can double its size in 5 days and a mat of medium sized plants may contain 2 million plants per hectare that weight 270 to 400 tone (Rezania *et al.*, 2015). It can flower throughout the year and releases more than 3000 seeds per year (Gopal, 1987; Rezania *et al.*, 2015) and the seeds are long-lived, up to 20 years (Gopal, 1987). When seeds may not be viable at all sites, it commonly colonizes new areas through vegetative reproduction and propagation of horizontally growing stolons. In the early stages of infestation, the weed takes a foothold on the shoreline in the areas where native aquatic plants thrive (Gichuki *et al*., 2012). However, it is not restricted to shallow water, unlike many submerged and emergent macrophytes, because its roots are free-floating near the surface (Villamagna and Murphy, 2010).

Water hyacinth causes a significant ecological and socio-economic effects (Villamagna and Murphy, 2010). The weed forms thick mats over the infested water bodies which causing hindrance to water transport, disrupting hydro-electric operations, blockage of canals and rivers, increased evapotranspiration, reducing water quality, interference with fishing, irrigation, navigation and reduction of biodiversity (Senayit *et al.*, 2004). Comprehensive estimation on economic impacts of water hyacinth in the affected areas of the Ethiopian water bodies have not been done yet. However, in Wonji-Shoa Sugar estate, from 2000 to 2013 a total of US$ 100,000 was spent to control the wed (Yirefu *et al*., 2014). Thus, controlling this aggressive weed using different techniquesis were crucial to alleviate its negative impact on biodiversity and socio-economic attributes. Globally, several control methods have been adopted to manage water hyacinth. The mechanical, manual, chemical and biological controlling methods are commonly used (Harley *et al.*, 1996; Gutiérrez *et al.*, 2000; Julien *et al.*, 2001).

2. Social Impacts of Water Hyacinth

2.1. Impacts of water hyacinth on human health

Floating mats of water hyacinth support organisms that are detrimental to human health. The ability of its mass of fibrous, free-floating roots and semi-submerged leaves and stems decrease water currents and helps increase breeding habitat for malaria causing anopheles mosquito as evidenced in Lake Victoria (Minakawa *et al*., 2008). According to Yirefu *et al.* (2007) based on the information obtained from Wonji Hospital malaria is still one of the major fatal diseases in the area that is supported by the stagnant water resulted from the impeding effect of water hyacinth. Mansonioides mosquitoes, the vectors of human lymphatic filariasis causing nematode Brugia, breed on this weed (Varshney *et al*., 2008). Snails serving as a vector for the parasite of Bilharzia reside in the tangled mat of this weed (Borokoni and Babalola, 2012). The weed also blocks access to water points and has been linked to an increase in cholera and typhoid. For example, from 1994 to 2008, Nyanza Province in Kenya, which borders Lake Victoria accounted for a larger proportion of cholera cases than expected given its population size (38.7% of cholera cases versus 15.3% of national population) (Feikin *et al*., 2010). The increased incidences of crocodile attacks have been attributed to the heavy infestation of the weed which provides cover to the reptiles, poisonous snakes, crocodiles and hippos (Patel, 2012).

2.2. Impacts of water hyacinth on water transport and recreation

Access to harbors and docking areas can be seriously hindered by mats of water hyacinth. Canals and fresh water rivers can become impassable as they clog up with densely intertwined carpets of the weed (Ndimele *et al.*, 2011). In the Wouri River Basin of Cameroon the livelihood of close to 900,000 inhabitants has been distorted (Mujingni, 2012). The entire Abo and Moundja Moussadi creeks have been rendered and impassable by the mats of the weed which leads to a complete halt in all the socio-economic activities (Mujingni, 2012). According to the report of Cho and Tifuh (2012) riparian communities in Cameroon**,** as part of their social activities like recreational benefits from the river; boat racing; swimming and site seeing were not possible in water hyacinth infested areas. Based on the study of Mujere (2016) water hyacinth was becoming a serious hazard to lake transport on Lake Victoria as large floating mats of water hyacinth form and this causes difficulty in navigation. This has grave implications such as failure to transport essential commodities from one landing site to another. In Uganda, residents of some islands such as Kasanje and Busi depend on water transport to take the sick to hospitals located in the mainland, for example, in Entebbe but when the weed blocks the way, deaths are common (Mujere, 2016).

3. Economic Impacts of Water Hyacinth

3.1. Impacts of water hyacinth to agriculture and fisheries

Dense infestations of water hyacinth restrict water flows in rivers and irrigation channels, interfere with irrigation equipment and have been known to cause structural damage to bridges (Jones, 2009). Reduced irrigation flow can indirectly cause loss on field crops but there can also be direct loss on paddy crops by suppressing the crop, inhibiting germination and interfering with harvesting (EEA, 2012; Patel, 2012). In Ethiopia, water hyacinth caused wastage of water through excessive evapotranspiration that would be used for sugarcane production (Yirefu *et al*., 2007).

Water hyacinth slows water flow by 40 to 95% in irrigation channels (Jones, 2009). In India in the Brahmaputra River, it has also blocked irrigation channels and obstructed the flow of water to crop fields (Patel, 2012). Furthermore, in West Bengal, water hyacinth causes an annual loss of paddy rice by directly suppressing the crop, inhibiting germination and interfering with harvesting (EEA, 2012). According to the report of Rakotoarisoa (2017) at Lake Alaotra, rice fields were invaded, inhibiting the germination, suppressing the crop and eventualy interfering to harvest the crop. Cultivation of teff *(Eragrostis tef),* chickpea, grass pea and maize has been impacted around the shore in LakeTana (Erkie, 2017)**.** As cited by Endeshaw (2018) Ethiopian Environment and Forest Research Institute reported that, the water hyacinth is highly infested at the coast of Dera, Fogera, Libokemkem, Gondar Zuria and Gorgora Woredas. In cause of water hyacinth the rice production of Dera, Fogera, Libokemkem, Gondar Zuria and Gorgora were became too low because of the farm land were captured by this weed.In addition mat of water hyacinth during flooding and wave time makes rice production frustrating by totally covering the rice field and it makes the farmland more compacted due to its long root that makes the farm land difficult to plough (Dereje *et al*., 2017).

The floating water hyacinth mats limit access to breeding, nursery and feeding grounds for some economically important fish species (Villamagna and Murphy, 2010). Additionally, the dense mats could entangled with boat propellers and hence hampering fishing activities (Patel, 2012). According to Cho and Tifuh (2012) report, water hyacinth causes severe problems to fishers in the riparian communities. When weed infestation is present, access to fishing sites become difficult for riparian communities and this negatively affect the life of the community as their livelihood solely rely on fisheries. Similarly, in Lake Naivasha, water hyacinth has a negative impact on the economic status of the fisher community (Waithaka, 2013). In Lake Victoria, fish catch rates on the Kenyan section decreased by 45% because of water hyacinth mats blocked access to fishing grounds and increased costs (effort and materials) of fishing (Kateregga and Sterner, 2009). Furthermore, due to water hyacinth infestation, fishing has become almost impossible task in Nigeria (Ndimele *et al*., 2011).

According to Wassie *et al*. (2014) report,water hyacinth infestation has been covered about 34,500 ha (15% of the Northern shore of the Lake Tana). Consequently, all the fishers changed their landing site because of water hyacinth expansion and obstructs their fishing activities (Erkie, 2017). As a result, the decline of large barbs has been observed presently in Lake Tana, which is got shallower and shallower due to the worst weed (water hyacinth). Furthermore, the catch per unit of effort of *Labeobarbus* in 2010 had sharply declined to 6 kg per trip in comparison with 28 kg per trip in 2001 and 63 kg per trip in 1991-1993 (63 kg per trip) (Brehan *et al.*, 2011). In the area of severe infestation, fishing is difficult especially around the shore area, this is because of covering the fishing gear by water hyacinth and the gill net is lost while this could strongly affect fishers that use artisanal fishing boat (Dereje *et al*., 2017).

3.2. Impacts of water hyacinth on water quality

Mats of water hyacinth prevent the transfer of oxygen from the air to the water surface or decrease oxygen production by other plants and algae (Villamagna and Murphy, 2010). Water hyacinth infested areas showed low values of dissolved oxygen ranged from 1.02 to 3.60 mgL^{-1} (McVea and Boyd, 1975; Masifwa *et al.*, 2001). The shoreline areas without water hyacinth have high mean concentration of dissolved oxygen (1.96±0.71), compared to the shoreline areas with water hyacinth (5.89±0.85) (Mironga *et al*., 2012). When the plant dies and sinks to the bottom the decomposing biomass depletes oxygen content in the water body due to the high oxygen consumption of rotting plant biomass (EEA, 2012). Dissolved oxygen levels can reach dangerously low concentrations for fish that are sensitive to such changes. Furthermore, low dissolved oxygen conditions catalyse the release of phosphorus from the sediment which, in turn, accelerates eutrophication and can lead to a subsequent increase in water hyacinth or algal blooms (Bicudo *et al*., 2007). Death and decay of water hyacinth vegetation in large masses deteriorate water quality (Ndimele *et al*., 2011). The most apparent environmental impact of water hyacinth infestations that affect the riparian community directly is the degradation of water quality by its foul smell and debris (Cho and Tifuh, 2012). The thick mats of water hyacinth lead to an increase in water turbidity due to the constant rotting of the mat base (Villamagna and Murphy, 2010). According to Mironga *et al.* (2012) water hyacinth infested area showed low pH values ranging between 6.7 -7.1, while those without water hyacinth had higher values ranging from 7.4-7.95. Free carbon dioxide was also higher in the water hyacinth infested areas with values ranging from 23.97-34.97 mgL^{-1} compared to non infested areas (3-20 mgL^{-1}) (Mironga *et al.*, 2012). However, according to the reporte of Dereje *et al*. (2017) in lake Tana, Ethiopia values of physico-chemical characters of the water in the lake were not statistically significance difference between the weed infested and non-infested sites.

3.3. Impacts of water hyacinth on hydropower plants

Water hyacinth causes high water losses through evapotranspiration and blocking turbines. The owen Falls hydropower scheme has suffered from the impact of the weed, hence plenty of time and money has been invested to clear and prevent the weed from entering the turbines, which may cause damage and power interruptions (ITDG, 1997). On Owen Falls hydropower scheme, water hyacinth caused damage to water coolers and generators, prompting the power utility company to switch off generators for maintenance, and about 15 Megawatts of electricity were lost causing power cut in an urban area of Ethiopia (Yirefu, 2014).

Many large hydropower schemes are suffering from the effects of water hyacinth. It is now a major problem in some of the world's major dams. Dams feeding the city of Harare have pronounced infestations of the weed (Mujere, 2016). The Owen Falls hydropower scheme on Lake Victoria is a victim of the weeds (Minakawa *et al*., 2008). The hydropower dams on the Shire River in Malawi also frequently forced to stop production due to clogging of the water cooling system by this weed (Wise *et al*., 2007). The Kariba dam which straddles the Zambia-Zimbabwe border on the Zambezi River and *Koka Lake* hydropower dam in Ethiopia suffer from the rapid reproduction of water hyacinth (Senayit *et al.*, 2004). In addition, Ethiopian Electric Power Corporation (EEPC) has reported this plant as a problem and disrupting their operation at the three hydropower stations located along the Awash River (Samuel and Nestanet , 2014).

Studies have shown that, the dense cover of water hyacinth enhances evapotranspiration (Mailu, 2001). The rate of water loss due to evapotranspiration can be as much as 1.8 times than that of evaporation from the same surface but free of plants (Haider, 1989). This has great implication where water is already scarce. The estimated water loss due to this weed from the highly infested water reservoirs that are used directly for irrigating the fields was ranged between 393,660 to 2,945,160 m^3 (Howard and Matindi, 2003). Such impacts of the weed were also reported in different countries (Howard and Matindi, 2003). Increased water loss by water hyacinth leads especially in shallow lakes such as Lake Alaotra to a drop in water level. It is estimated that the flow of water in the Nile could be reduced by up to one-tenth due to increased losses from evapotranspiration by water hyacinth in Lake Victoria (Ndimele *et al*., 2011). Allen *et al*. (1997) also indicated that this effect can result in loss up to 13 times from that of a free water surface with a minimum rate of 2.5 times. In Ethiopia, water hyacinth caused wastage of water through excessive evapotranspiration that would otherwise be used for sugarcane production (Yirefu *et al*., 2007).

4. Management Options of Water Hyacinth

4.1. Manual/mechanical control

Mechanical control refers to the use of machinery such as mechanical mowers, crusher boats, destruction boats, dredgers and weed harvesters which are designed to physically cut, shear, shred, crush, press, lift or remove and transport aquatic plants and associated organic material from water bodies (Cho and Tifuh, 2012). Mechanical cutting and harvesting are practical for large-scale (several acres) vegetation removal because they remove plants from large areas in a relatively short time. Mechanical cutting and harvesting are non-selective and could eliminate valuable fish, plants and wildlife habitat within the target area. However, recently some 75 km of the Guadiana River in Spain was controlled mechanically (Têllez *et al.,* 2008).

Mechanical control includes harvesting by hand or machine (Villamagna and Murphy, 2010). The use of machinery to remove water hyacinth from water bodies is the most effective non-polluting control method (Mara, 1976). The main advantage of the use of mechanical harvesting is the simultaneous removal of nutrients and pollutants from the water body (Wittenberg and Cock, 2001).

Manual control involves the removal of water hyacinth by uprooting weeds with hands or cutting with cutlasses. However, the method is very risky because of the existence of some animals such as snakes, alligators and crocodiles which live underwater hyacinth mats. Furthermore, it is time-consuming and labour intensive (May *et al.,* 2003) but if implemented systematically, it may be of great value to reduce a moderate stand of the weed (Labradar, 1995). Manual removal was used in South Africa (Hill and Coetzee*,* 2008). According to Mujere (2016) study, manual removal of the weeds or pulling through nets using hands and/or rakes was done in Lake Mutirikwi (90 km^2) in Zimbabwe. Based on Yirefu *et al.* (2007) the management of the weed at Wonji-Shewa Sugar Factory indicated that the factory has been practicing manual and mechanical removal of the weed from the canals periodically and left to dry at the border of the canals. The fisher-folk communities around Lake Naivasha also identified key infested sites and control the weed manually (Mironga *et al.*, 2011). The Owen falls hydropower scheme at Jinja on Lake Victoria is a victim of water hyacinth's rapid proliferation and physical removal was practiced to control the weed (Mailu, 2001). In Ethiopia, Lake Tana water hyacinth control were done physically by human hands, wooden sticks, reed boats and a few instances motorized boats (Edwards, 2013).

4.2. Chemical control

The three most commonly used aquatic herbicides are 2,4-D, Diquat (6,7-dihydrodipyridol) and Glyphosate (Martínez Jiménez, 2003). All these herbicides are absorbed through the leaves and are quickly transported throughout the whole plant, killing all parts of the weed (Lindsay and Hirt, 1999). Herbicide applications are usually less expensive than mechanical control but may have to be repeated on an annual basis (GISD, 2006); owing to the fact that once plants are removed, light penetration increases, favoring the germination of water hyacinth seeds and therefore new water hyacinth re-infestation. The limitation of this method remains its negative impact on the environment and health-related effects, especially where people collect water for drinking and washing. An additional problem of chemical control is that water hyacinth decomposes and further enriches the water and eventually algal blooms will replace the weed (Mujere, 2016).

The herbicide 2-4-D was used in Lake Chivero from 1971 to 1985, after which time, it was banned. Lake Chivero was observed to be reinfested with hyacinth 6 months after spraying with 2-4-D, due to poor transport of the chemical in the stems from the parent shoots to the offshoots (Chikwenhere, 2001). According to Uka *et al.* (2007), a few trials were undertaken at Ere fishing channel South-west Nigeria. The application of Glyphosate gave rise to total mortality of water hyacinth within 14 days. Herbicidal control, using formulations containing the active ingredient glyphosate, is still used to control water hyacinth in some of the larger dams and river systems in South Africa. Based on the experiment of Aklilu *et al*. (2018) the chemicals particularly, acetic acid and glyphosate showed better efficacy in suppressing water hyacinth tissue growth when applied at an experimental site.

4.3. Biological control

The biological control of water hyacinth began in the 1960s and involves control of water hyacinth through the use of host-specific insects, moths or pathogens which are natural enemies of the weed and imported from the point of origin of the weed (DeLoach and Cordo,1976). Biological control remains the most cost-effective and environmentally friendly technique for the sustainable control of water hyacinth (van Wyk and van Wilgen, 2002). Adult beetles feed on leaves which increase transpiration and places the plant under stress. The weevils *Neochetina eichhorniae* Warner and *Neochetina bruchi* Hustache (Center *et al.,* 1982) are two species that have provided the best results. for biological control. Other biological agents including the fungi *Alternaria eichhorniae* and *Cercospora piaropi* (Jiménez and Charudattan, 1998*)* and the moths *Niphograptaalbiguttalis* and *Xubidainfusellus* were used to control the weed (Julien *et al*., 2001). Marked successes with biological control agents have been reported from many parts of Africa and the world, notably at Lake Chivero (Zimbabwe), Lake Victoria (Kenya), Louisiana (USA), Mexico, Papua New Guinea and Benin (Gichuki *et al*., 2012).

A combination of weevil and fungal attack on water hyacinth has been applied in Lake Chivero. The weevils *Neochetina bruchi* and *Neochetina eichhornia* have been identified as absolutely specific to control the hyacinth in Lake Victoria and Chivero (Mujere, 2016). The weevils were used for the control of water hyacinth in China. A release of 1000 insects per (1000 m^2) in two sites exerted an efficacy around 90% of the water hyacinth infestation (Ding *et al*., 2001). According to the experiment of Adugnaw *et al.* (2017) in greenhouse level, *Tricothecium roseum*, *Aspergillus flaves*, *Trichoderma spp*, *Fusarium spp*, *Rhizocotonia spp*, *Aspergillus niger* and *Trichdoerma spp* fungi were promising to manage water hyacinth at above 26°C and at less than 25% humidity. The plant hopper, *Megamelus scutellaris* Berg (*Hemiptera: Delphacidae*), was the most recent agent that has been released in 2013 and impacting the plant in the cooler areas of South Africa (Hill and Coetzee, 2017). According to Yirefu (2017), *Neochetina bruchi* was considered as a promising candidate for control of water hyacinth under Ethiopian conditions. The principal drawback with biological control of water hyacinth is the time required to achieve control and in tropical environments, this is usually 2 to 4 years (Wittenberg and Cock, 2001).

4.4. Integrated management

Integrated control involves the combination of two or more control methods to achieve weed reduction. Integrated management programmes are site-specific and will depend greatly on the hydrological and nutrient status of the system, the extent of the infestation, the climate of the area and the use of the water body (Julien *et al.*, 2001). This method has been succesful in Tanzania mainly through the combination of biological control, manual removal, quarantine regulations and management of nutrient enrichment (Mallya *et al.*, 2001), where there has been a significant reduction in water hyacinth plant density, from 45 to 7 plants per 0.5 m^2 and the population by over 70% within a period of 3 years (Mallya *et al.*, 2001).

Jones (2001) developed an integrated management programme for the Nseleni River system in the more tropical region of South Africa. The key elements of this approach were primarily the appointment of a champion to drive the control programme, the involvement of all interested and affected parties on the river system, the division of the river system in to management units and the implementation of appropriate control methods for each of these management units. Using this integrated approach, some 19 km of river that was previously 100% covered by water hyacinth was initially cleared using mainly herbicide application and is maintained at 5% weed cover through biological control with occasional follow-up herbicide application around sensitive sites (water abstraction localities) when necessary.

Interactions between chemical and biological control have been demonstrated. Herbicides can be used to reduce the vigour of water hyacinth but without harming the biocontrol agent. Paraquat, glyphosate and 2,4-D have all been used to enhance the effects of *Neochetina* spp. Plant growth regulators also have this potential: paclobutrazol, for example, in combination with *N. eichhorniae* gave 95% control of water hyacinth in the USA but the weevil alone gave only 24% control in the 8-month study period (Van, 1988). It is also possible to use herbicides to reduce water hyacinth populations to low levels prior to the introduction of biocontrol agents, thereby giving the agents time to become established and better able to suppress regrowth of the weed. However, extensive herbicide applications in South Africa had a detrimental effect on colonies of *N. eichhorniae* (Cilliers,1991).

Conflicts of Interest

The authors declare no conflicts of interest.

5. Conclusion and Recommendations

Aquatic weeds have become an increasing concern in all water use types. Water hyacinth is one of the top ten most invasive aquatic plant species in the world. It is arguably the most noxious aquatic weed in the world, due to its ability to rapidly cover whole waterways and efficient survival strategies in extreme conditions. It also posed significant economic, social and environmental problems. These include hindrance to water transport, disrupting hydroelectric operations, blockage of canals and rivers, flooding, causing human health problems, increased evapotranspiration, interference with fishing and reduction in irrigation efficiency.

Different management strategies such as manual/mechanical, chemical and biological methods had been used to control the weed. Accordingly, manual removal was used in South Africa; Zimbabwe Lake Mutirikwi; Ethiopia Lake Tana, Wonji-Shewa Sugar Factory and Owen fall hydropower in Jinja at Lake Victoria. Chemical control was practiced in Zimbabwe Lake Chivero using 2-4-D; South-west Nigeria Ere fishing channel by glyphosate; South Africa larger dams and river systems by using glyphosate; Zimbabwe acetic acid and glyphosate control the weed at experimental site. Biological control was practiced in Zimbabwe Lake Chivero through a combination of weevil and fungi; Kenya Lake Victoria and China by two types of weevils (*Neochetina bruchi* and *Neochetina eichhornia*) and Ethiopia *Neochetina bruchi* and fungi at Rift Valley and in a greenhouse at the experimental level, respectively.

In some countries including Ethiopia, the management and control of water hyacinth was beyond the capabilities of local governments alone. Therefore, the involvement of multidisciplinary approach like the creation of awareness to the public in all aspects of the weed; application of integrated managemet technique particularly mechanical, manual and biological control measure should be implemented. It should be designed in a way that the highest political and administrative levels recognize the potential seriousness of the weed and leads the controling team.

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Management of Traditional Agroforestry Homegarden and its Contribution to Household Livelihood Diversification in Tembaro District, Southern Ethiopia

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Received: June 3, 2019 Accepted: August 28, 2019

Abstract: *Homegarden is more diverse and provides multiple products for farm households. The objective of this study was to record and describe management practices, identifying the contribution of homegarden to household livelihood, assess the structural arrangement as well as factors affecting species diversity of the practice at Tembaro district, Southern Ethiopia. For this study, socio-economic data were collected from 120 households by using semi-structured questionnaires. Structural arrangement data were collected during the field survey. A total of 29 woody species categorized under 22 families were recorded in the homegarden agroforestry of the study area. Woody species richness and abundance were significantly higher ($P < 0.05$) in richer household than medium and poor once in both study kebeles. Coffee arabica, Cordial africana, Persea americana and Mangifera indica are the most frequently recorded woody species in both sites. The highest diversity indices were recorded at Debub Ambukuna than Sigezo, due to environmental and socioeconomic factors. Species composition depends on the farmer's preference and attribute of preferred species. This study has identified three different vertical arrangements and 4-6 horizontal compartments in both study sites. The farm households have benefited with different outputs from this practice. To sustain production, farmers carried out different management practices. Each household's members have been participating in homegarden management. However, women have been involved in more responsibilities than other members in each study sites. Managing species diversity associated with different factors, socioeconomic once are the most determinants. Institutional intervention is important on infrastructural issues in growing and diversifying economically valuable plant species in homegarden agroforestry and to improve the rural community in facility service to encourage the exchange products effectively and efficiently. Further study is needed in management practices of each component in homegarden agroforestry and improvement of production and productivity obtained from the homegarden agroforestry.*

Keywords: Arrangement of homegarden, vegetable and spice crops, woody species diversity

1. Introduction

Homegarden is a traditional land-use system which is extensively practiced throughout the world (Wajtkowski, 1998). Homegarden agroforestry can be defined as land use system involving deliberate management of multipurpose trees and/shrubs in intimate association with agricultural crops and invariably livestock within the compounds of individual houses, the whole tree-crop-animal unit being intensively managed by family labor (Fernandes and Nair, 1986). It is found in most ecological regions of the tropics and subtropics, but a majority of them are in the lowland humid tropics (Fernandes and Nair, 1986; Nair, 1993). In homegarden agroforestry trees and crops provide numerous benefits to households, such as the production of building materials, food and firewood; generate family income and protect against soil erosion (Salam *et al*., 2000). Because of the high plant species diversity existing in homegardens, a wide spectrum of multiple-use products can be produced with relatively low labour, cash, or other external inputs (Soemarwoto, 1987; Christanty, 1990; Hochegger, 1998;; Das and Das, 2005). Woody species are very important components of homegarden that contribute to the livelihoods diversification (Tesfaye, 2005).

Homegarden agroforestry is characterized by high species diversity and have different vertical and horizontal arrangements. It usually encompasses 3-4 vertical canopy strata which results in intimate plant associations (Fernandes and Nair, 1986; Nair, 1993; Zemede and Ayele, 1995). Various studies have shown that broad-leaved trees dominated the upper story of homegardens in southern and other parts of Ethiopia (Zebene, 2003; Muktar, 2006; Yitebitu, 2009; Tesfaye *et al.,* 2010). It is also known that the middle story of these kind systems contains annual and perennial crop types (Jama *et al.,* 2006), while vegetables, spices, and herbs cover the ground layers.

Farmers employ indigenous knowledge in managing homegardens where management activities are mostly responsibility of women. For instance, study conducted by Fentahun (2008) in Amhara Region, shown that farmers carry out pruning, pollarding, lopping, weeding, fencing and etc. to manage tree species diversity in homegarden. In Ethiopia, homegarden agroforestry is widely practiced as a major source of daily food and income generation (Zemede, 2002; Tesfaye, 2005). Southern Nation's Nationalities and Peoples' Regional State is the most commonly known example of perennial-crop based homegarden in Ethiopian highland (Tesfaye, 2005). Tembaro district is among of the districts which widely practice homegarden agroforestry in Southern Nations, Nationalities and People's Regional State. Within districts where homegarden agroforestry is practiced, information on management practices, their contribution to sustainable livelihood to the local community of the area and factors influencing the management of homegarden is very limited or not available. Therefore, this study is an attempt in this direction for the district to illuminate information on the management practices, contributions to household livelihood as well as factors affecting the management of homegarden in order to create an effective way of household contributions and appropriate management techniques for diverse species of homegarden agroforestry.

1. Materials and Methods

2.1. Description of the study area

The study was conducted in Tembaro district in Kembata Tembaro Zone, Southern Ethiopia. Geographically, it is located between 37º36'32'' to 37º21'5'' E and 7º11'8'' to 7º21'51'' N. The altitude of the study area ranges from 800 to 2600 meter above sea level (Figure 1).

Figure 1. Map of the study area

2.2. Study site selection

Tembaro district encompasses three agro-ecological zones, from which Kola and Woyena dega cover the largest proportion. Two kebeles were selected purposively from the above agro ecological zones, namely Sigazo kebele from midland and Debub Ambukuna from lowland based on the presence of extensive homegarden agroforestry practice. Before the field data collection, a preliminary reconnaissance survey and direct field observations were conducted to obtain similar data prior to a detailed survey.

2.3. Data collection

Formal survey data collection was conducted on the sample households with the structured questionnaires in each selected village. Both primary and secondary data sources were used as an information tool. At the household level, the necessary data related to the homegarden management and its contribution to household livelihood was collected using a structured questionnaire through interviewing the household heads. To assess farmers' management practices and socioeconomic factors affecting the practice within the study area, then all farmers who practiced homegarden were stratified based on wealth status using the record of total households living in the study area using livelihood standard by the help of key informants. Following stratification of households into wealth category, from each wealth class respondents were randomly selected for the household survey. Then six percent sample households were employed in the interview at each wealth class. About 120 respondents were used for household interview.

Data on plant inventory, plant use, species abundance and the total count of individuals of each species were collected from entire gardens of 120 randomly selected households to estimate its richness, abundance and frequencies in garden level. The local name of the plant species found in the sample plots was identified and recorded with the help of key informants and scientific nomenclature was carried out using plant identification manuals and books namely useful trees and shrubs of Ethiopia (Azene, 2007) and Flora of Ethiopia and Eritrea (Edwards, *et al.* 1995). Homegarden structure characterization carried out accordingly to collect structural arrangement data of homegarden. The number of vertical strata and the plant species occupying each stratum in each site was recorded following the classification of Millate (1998). Accordingly, six different vertical strata; <1 m, 1-3 m, 3-5 m, 5-7 m, 7-9 m, and >9 m were considered.

2.4. Data analysis

Non-quantifiable elements such as events, behaviors, activities, meanings from the informal survey were interpreted, analyzed, and synthesized using descriptive statistical analyses. Quantitative data obtained from household questionnaire survey was entered to the computer, analyzed and synthesized using SAS software. One-way ANOVA was used to test whether there is a significant difference in income generated from homegarden agroforestry, woody species diversity and richness among as well as between the different wealth groups. Microsoft-Excel was also used to generate tables and graphs. These data were organized and results were presented in frequency and tables.

2.4.1. Shannon diversity index (H')

It relates the proportional weight of the number of individuals per species to the total number of individuals for all species. Shannon diversity index was calculated as:

$$H' = -\sum_{i=1}^{s} \mathrm{Pi} \ln \mathrm{Pi} \qquad [1]$$

Where

H′ = Shannon-Wiener Diversity Indexes; s = number of species; Pi = Proportion of individuals or abundance of the i^{th} species expressed as a proportion of the total cover; Ln = log base (natural logarithm).

2.4.2. Equitability (evenness) index

Evenness (equitability) index (J) was calculated following the formula indicated below.

$$\text{Equitability } (J) = H'/\mathrm{Hmax} \qquad [2]$$

Where

J = Evenness; H’ = Shannon-Wiener Diversity Index; Hmax = lnS; S = total number of species in the sample.

3. Results and Discussions

3.1. Socio-economic and demographic characteristics

From a total of 120 households interviewed for this study, male respondents accounted for 90.8% and the rest were females of the sampled population, 38% were illiterate, 26% elementary school (grade1-4) complete, 23% second cycle (grade 5-8 complete) and the rest 13% were high school and above. All respondents were categorized into three age categories. The lower age category (28-45) year accounted for 54% and the rest medium (46-64) and old (above 64) accounted for 39% and 7%, respectively. The mean, maximum, and minimum land holding of the respondents was 0.82, 6 and 0.25 hectares, respectively. The occupation of people in the study area was mixed agriculture/crop cultivation and animal husbandry/ which are common farming practices.

3.2. Woody species diversity

3.2.1. Component arrangement

Homegarden agroforestry in the study area is an assemblage of different life forms with the compartments of different vertical and horizontal arrangements. The upper story was dominated by *Cordia africana*, *Albizia gummifera*, *Millettia ferruginea*, *Persea americana* and *Mangifera indica*; the middle story occupied with ensete, coffee, maize and banana while vegetables, spices, and herbs cover the ground layers. This study identified three different vertical arrangements or strata in both study sites. Similar multilayer vertical structures with 3-6 vertical strata have been reported in different tropical homegardens (Gajaseni and Gajaseni, 1999; De Clerck and Negreros-Castillo, 2000; Albuquerque *et al*., 2005; Fentahun, 2008). Various studies have shown that broad-leaved trees and fruit tree crops are among woody species that dominated the upper story of the coffee-based agroforestry practice and homegarden in southern and other parts of Ethiopia (Badege and Abdu, 2003; Zebene, 2003; Muktar, 2006; Yitebitu, 2009; Tesfaye *et al.,* 2010). It is also known that the middle story and of these practice comprise Enset, coffee and maize (Jama *et al.,* 2006) while vegetables, spices, and herbs cover the ground layers (Zebene and Ågreen, 2007).

Besides the vertical strata, homegarden in the study area is characterized by horizontal compartment where different crops receive different management practices. In the present study, 4-6 horizontal arrangement was identified in most homegarden. Most prominent of these management zones common in the majority of homegarden include distinct compartments for enset, coffee, root and tubers and vegetables. Spices and medicinal plants often planted in plots close to the house next to beehives. Enset suckers are also raised next to spices and medicinal plants for special protection such as composting and watering in the dry season. Distance from home position, size, crop composition, and planting pattern of the garden are the principal determinants (Kumar and Nair, 2004). The arrangement of components in this homegarden is not haphazard but a designed one. Such an arrangement of the various management units indicates farmers’ indigenous knowledge of planting pattern. Many authors have reported that distinct horizontal zones occur in the homegarden, and that their location, size and plant species composition reflect deliberate management strategies (Abdoellah, 1990; Zemede and Ayele, 1995; Mendez *et al*., 2001).

3.2.2. Woody species diversity indices

Analysis of species diversity was carried out for both locations; its value varies in both sites depending on different socioeconomic factors.

Table 1: Richness and abundance of woody species in homegardens of two kebeles in Tembaro District of Ethiopia

Sites	Altitude	Richness		Abundance	
		Total	Mean (±std)	Total	Mean (±std)
Sigezo	1820-2000	25	8.3b±2.1	9138	152.3b ±73.6
Debub Ambukuna	1506-1650	29	9.6a ±1.8	12558	209.3a ±84.9
Overall mean		27	8.95±1.95	10848	180.8±79.25

Means in column followed by the same letter/s are not significantly different at P<0.05

Woody species recorded in homegarden of the study sites were 29, which categorized under 22 families. Fabaceae family had the highest number of species (4) followed by Rutaceae and Euphorbiaceae both with 3 species. The rest families had only one species for each. Generally, woody species richness was significantly higher (P < 0.05) in Debub Ambukuna than Sigezo. The abundance of woody species in the present study varied between two sites.

Species richness and abundance were also calculated for the three wealth classes in both sites. Woody species richness was significantly (P<0.05) higher in gardens of rich than medium and poor wealth categories at both sites. Similarly, it was significantly higher for the medium wealth category than the poor. From all wealth categories, the highest species richness and abundance were recorded in Debub Ambukuna for rich and the lowest in Sigezo for poor class. However, there was no significant difference (P > 0.05) among rich and medium wealth categories at both kebeles for species abundance (Table 2).

In order to get a better picture on the extent of woody species diversity, diversity indices were calculated in both study sites respecting to agro-ecological base and wealth classes. The highest Shannon and Simpson diversity indices were recorded at Debub Ambukuna. Species evenness also showed similar trend like Shannon and Simpson indices in terms of species diversity. Generally, woody species diversity was higher in homegarden at lowland site than midland (Table 3). Woody species diversity was significantly higher in rich than medium and poor wealth categories. Similarly, the three diversity indices were significantly higher for the medium wealth category than the poor. However, there was no significant difference (P > 0.05) among rich and medium wealth categories at Sigezo kebele for Simpson diversity index (Table 4). Farmers grow diverse woody species in their homegarden for different services. Wide variations in species assemblages of different geographic/eco-climatic regions are apparent (Kumar and Nair, 2004). The number of species in homegarden from different parts of the world ranged from 60 (Zemede and Zerihun, 1997, in southern Ethiopia) to 324 (Mendez *et al*., 2001, in Nicaragua).

In the present study, the mean woody species richness and woody species diversity per homegarden varies within and between sites. The difference in species richness and diversity between sites could be the result of differences in agro-ecology of the sites whereas within site variation related to garden size (land), management skill and household species preference for various purposes. It is in line with the result reported from Beseku, Ethiopia by Motuma *et al.* (2008). The mean number of woody species per homegarden in this study (8.95) is lower than that (11.0) reported by Zemede and Ayele (1995) from 111 sample homegarden from different agro-ecological zones in Ethiopia and (16.0) reported for Sidama homegarden (Tesfaye, 2005).

Table 2: Richness and abundance of woody species in garden`s of different wealth categories in different kebeles in Tembaro District of Ethiopia

Wealth category	Sigezo Kebele		Debub Ambukuna Kebele	
	Richness	Abundance	Richness	Abundance
Rich	9.6a ±2	213a ±262	10.7a ±1.2	285a ±130
Medium	8.3b ±2.2	155a ±132	9.6b ±1.5	236.4a±105
Poor	7.1c ±1.4	88.5b ±35	8.5c ±1.4	107b ±21
Overall mean	8.3±2.1	152.3±175.6	9.6±1.5	209±85

Means in column followed by the same letter/s are not significantly different at P<0.05

Table 3: Shannon, Simpson and Evenness diversity indices of two kebeles in Tembaro district of Ethiopia

Kebeles	Altitude	Shannon index	Simpson index	Evenness
Sigezo	1820-2000	0.81b +0.28	0.40b +0.14	0.43b +0.17
Ambukuna	1506-1650	1.09a +0.27	0.54a+0.12	0.46a +0.12

Means in column followed by the same letter/s are not significantly differences at P<0.05

Table 4: Shannon, Simpson and Evenness diversity indices of different wealth categories in two kebeles in Tembaro district of Ethiopia

Kebeles	Wealth	Shannon	Simpson	Evenness
Sigezo	Rich	0.81c±0.24	0.40b±0.12	0.46b±0.12
	Medium	0.70c ±0.23	0.39b±0.13	0.33d±0.09
	Poor	0.67c ±0.22	0.35b ±0.14	0.32d ±0.12
Debub Ambukuna	Rich	1.32a±0.20	0.62a±0.08	0.58a ±0.09
	Medium	1.098b ±0.14	0.57a ±0.05	0.45bc±0.07
	Poor	0.84 c±0.19	0.42b±0.12	0.36cd ±0.09

Means in the same column followed by different letters are significantly different (P<0.05)

3.3. Management of homegarden agroforestry

Woody species in the study area receive different management practices by household members. Activities like pruning, thinning, coppicing, pollarding, composting, weeding, digging or hoeing and planting material production taking place for woody species management. This is in line with the result of Tefera (2010); Fentahun (2008) who reported in most part the rural people uses different management practices. In the study area, farm households have well-founded indigenous knowledge to manage each component of homegarden. Farmers manage woody species mainly to reduce resource competition, enhance growth, and to achieve the aim of targeted production. These productions continued through the integration of multipurpose woody species, which are economically feasible and socially acceptable. A similar finding was reported by Negussie and Mesele, (2006) Wonago district, Southern Ethiopia. Zemede (2002) also reported that homegarden management depends on the indigenous knowledge of the community and the household's partners.

However, there are several factors that hinder the rising of germplasm and management of the practice in the study area. In order to solve such problems, local farmers traditionally use practices such as fencing, guarding, cultural practices (sanitation) and the application of insecticides to reduce the impact of damages. Farmers of the study site have different sources of germplasm. According to the present study, self-regeneration, own nursery, Ministry of Agriculture and others (sharing between homegarden owners) were the main sources. The finding of the study is comparable to earlier studies done elsewhere. For instance, Sunwar (2003) reported the majority of sources for planting materials for homegarden are self- established by farmers themselves. Few fruit, coffee and *Gravilia robusta* seedling received from government nurseries in both study sites. Similarly, Sunwar (2003); Fentahun (2008) reported farmers obtained homegarden species from government organization nursery site.

Farm households preferred some woody species to integrate deliberately to homegarden based on their desirable functions. Accordingly, *Coffee arabica*, *Cordia africana*, *Persea americana*, *Mangifera indica*, *Albizia gummifera* and *Grevillea robusta* are highly preferred tree species by the farm households. The species preferences in the homegarden depends on their economic advantages, ability to fertilize the soil, fast decomposition rate, sparse crown, and absence of severe competitive effects with the other homegarden components. Similar research has been conducted in Nigeria, which suggests that for their best trees, farmers had a wide range of preferences and often gave more than one character (Lovett and Haq, 2000).

Farmers were encountered with a number of problems while establishing and growing woody species in homegarden agroforestry. Such damage and control measures are not restricted to current study area. For example, in Bangladesh major problem that farmers faced in tree establishment and management were the damage caused by animals, storms, and insect pests (Alam *et al*., 2005; Zaman *et al*., 2010). However, depending on the local experience there could be a number of approaches applied to protect farm trees in homegarden. For instance, farmers in the study area solve the problems of insect pest and disease using insecticides. On the other hand, fences are constructed to protect woody species from animal damage while guarding was a recommendable solution to reduce damage from thieves and wild animals.

3.4. Contribution of homegarden agroforestry to household livelihood

Homegarden of the study sites is an assemblage of annual and perennial crops, which are major sources for diverse products to human use. Farmers in the study area manage homegarden for various purposes; it has a wider contribution to livelihood diversification. It plays a vital role in contributing to the livelihood of respondent households. In both study sites, farmers are growing different species in their homegarden primarily for household consumption and to a lesser extent income generation. The plant species diversity in homegarden plays a fundamental role in the provision of diversified products for household utilization. In a similar manner, diversified outputs in homegarden have been reported across Ethiopian gardens (Zemede and Ayele, 1995). Studies made elsewhere also support the view of sampled farmers on the benefits of homegarden cotribution. The number of functional units in the homegarden of the study area is also comparable to Sidama homegarden (10 functional units per homegarden) (Tesfaye, 2005). Similar benefits have been reported from elsewhere (e.g. Gebauer, 2005).

As observed in field survey, homegarden size varied depending on different socioeconomic characteristics. For instance, rich and medium households' homegarden with better management and species composition than a poor farmer, thus the former two categories have got high income from diverse plant species than the later. The mean annual income (2009-2011) from homegarden was showed that there is significantly different between wealth categories within a study site (Table 5). Rich farmers got higher mean annual income (12942.9 Birr), than medium (7915.2 Birr) and poor (5185.9 birr) across study sites.

Table 5: Annual income (2001-2003 EC) obtained from homegarden in Tembaro District of Ethiopia

Sites	Wealth category	Mean(± std) income
Sigezo	Rich	11279.3b ±4419.7
	Medium	7170.4cd±2361.2
	Poor	4991.5d±1301.7
Debub Ambukuna	Rich	14606.5a ±3405.7
	Medium	8660c ±2549.2
	Poor	5380.3d ±957.7

Means in the same column followed by different letters are significantly different (P<0.05)

Cash crops and fruit trees play a vital role in cash income generation in the study area in addition to household consumption. Coffee, ginger, avocado and mango are major sources of income while satisfying household consumption. The income difference between households was may be wealth status difference, knowledge of desirable species integration and composition of economically important species and the size of homegarden and households preference for specific crops. Similarly, in Indonesia, total annual income generated from 6.6% to 55.7% depending on the size of the homegardens, family needs and species composition (Soemarwoto, 1987).

3.5. Factors Influencing Plant Species Richness and Diversity in Homegarden

Land availability is an important factor that determines the development of each component of homegardens. The average size of homegarden obtaiend from the study site was 0.41 ha per household (Table 6). As Homegarden size increased plant species richness and diversity were increases, where it offers the space to integrate compatible plant species. A positive relationship between garden size and species richness has been documented by many workers, e.g. Tesfaye, (2005) in Southern Ethiopia, Abdoellah *et al*., (2002) in Indonesia, Das and Das, (2005) in India, and Sunwar *et al*., (2006) in Nepal. Wealth status was another factor that influenced plant species richness in homegarden. Rich households cultivate significantly higher (P< 0.05) number of plant species than medium and poor households (Table 6). Several studies have reported the influence of wealth on the tree density and tree species richness on farmlands (*e.g*. Den Biggelaar, 1996; Zebene, 2003; Tesfaye, 2005). However, Warner (1993) noted that a lack of capital may hinder a farmer from obtaining a preferred species or a large number of seedlings, although it does not prevent him from planting trees.

Table 6: Homegarden size and plant species in different wealth categories in Tembaro district of Ethiopia

Wealth	Sigezo (higher altitudinal site)		Debub Ambukuna (lower altitudinal site)	
Categories	Average size of homegarden (ha)	Average plant species	Average size of homegarden /ha	Average plant species
Rich	0.55a ± 0.17	12a ± 0.95	0.50a ± 0.11	14.5a ± 0.75
Medium	0.42b ± 0.14	9.6b ± 0.25	0.38b ± 0.15	11.0b ± 0.70
Poor	0.34b ± 0.11	7.3b± 0.40	0.31b ± 0.10	8.8b ± 0.40

Means in column followed by the same letter/s are not significantly differences at P<0.05

Age of the respondents was another socio-economic factor which influenced plant species richness in homegarden in the study area. As it was observed from the survey result, older respondents have significantly higher (P<0.05) species richness than the younger ones (Table 7).

Table 7: Plant species in homegardens of different age category of households Tembaro District of Ethiopia

Age category (years)	Sigezo Kebele	Debub Ambukuna Kebele
	Plant species	plant species
Lower (28-45)	8.3c ± 0.40	9.8c ± 0.40
Medium (46-64)	9.9b ± 0.25	11.6b ± 0.70
Old (>64)	11.2a ± 0.95	13.5a ± 0.75

Means in column followed by the same letter/s are not significantly differences at P<0.05

In the study area different socioeconomic factors were stated by interviewed respondents, that influnce the abundance and richeness of the species. Villages of the lower site have a higher abundance of coffee and fruit tree species than the upper altitudinal site (Table 1 and 3). Location of market place negatively or positively affected the farmers in growing woody species in homegarden (Zebene, 2003; Tesfaye 2005; Sandya Kumari, 2009). Altitude is an important ecological factor that influences plant species richness in homegarden in the study area. Debub Ambukuna in lower altitudinal has higher plant species richness than Sigezo in the higher altitudinal site. Species richness is generally said to decrease with increasing elevation due to decreasing mean temperature. This is in line with the work of Karyono, 1990; Hodel *et al*., 1999 and Krebs, 1985.

4. Conclusion and Recommendations

4.1. Conclusion

Traditionally, farm households manage homegarden by employing different options to achieve sustainable production. Activities like pruning, thinning, coppicing, pollarding, composting, weeding, digging or hoeing and planting material production were taking place in garden management. The growing of woody species in homegarden depends on farmers' preference. Accordingly, farmers selected woody species in the order of *Coffee arabica*, *Cordia africana* and *Persea americana* followed by *Mangifera indica* based on the benefits they provide. Seedlings of the woody species planted were obtained from self-raised (own nursery), self-regeneration (under mother tree around the home), MoA and others. Livestock damage, disease, theft, insect pests and wild animals' damage were the main problems encountered during homegarden management. However, local farmers traditionally use practices such as fencing, guarding and application of organic pesticides to solve the problems. On the other hand, farm size, wealth, agro-ecology, age of household, and market and road access were the major factors determining species composition in homegarden agroforestry.

Homegarden agroforestry has a variety of contributions in improving the household livelihood. For instance, food crops, cash crops, fuelwood, animal feed, timber, household tools, medical plants, spices, farm implements, honey and uncounted ecological services such as soil fertility improvement, providing shade for living organisms, etc. are the contributions households obtained from homegarden agroforestry.

4.2. Recommendations

Based on the results of the present study the following recommendations are forwarded.

- Framers in the study area should be encouraged to use their indigenous knowledge in managing homegarden and assisted through extension services, to make them well equipped and used as a source of information center.
- Empowering experts to find a solution for the described constraints to promote and implementation of homegarden agroforestry in areas where it is advanced.

- Accessibility of infrastructure is a critical issue in growing and diversifying economically important plant species in homegarden agroforestry. Therefore, the intervention of institutions is needed to improve the rural community in facility service to encourage the exchange products effectively and efficiently.
- Further detailed study is required in management practices of each component in homegarden agroforestry and further improvement of production and productivity obtained from the homegarden agroforestry.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

Acknowledgements

We would like to extend our great appreciation to farmers and experts for devoting their precious time in providing information and sharing their knowledge for this study. We also would like to thank Dr. Zebene Asfaw for his assistance during research work.

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Assessment of Maximum Sustainable Yield and Optimum Fishing Effort for the Nile Tilapia (*Oreochromis niloticus L.*) in Lake Chamo, Ethiopia

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Received: August 16, 2019 Accepted: October 27, 2019

Abstract: *The study was conducted to estimate the maximum sustainable yield (MSY) and optimum level of fishing effort for Nile tilapia (Oreochromis niloticus) stock in Lake Chamo, Ethiopia. Data were collected from eight major landing sites of Lake Chamo for three days in a week for ten months (February to November, 2018). The total length, sample weight and total weight of O. niloticus caught by the fishermen and the fishing effort were the basic information collected from these sites. Totally, 7,570 O. niloticus samples were collected in 120 days. The FiSAT software was used to determine von Bertalanffy growth and mortality parameters. Jones length based cohort analysis model and length-based Thompson and Bell yield prediction models were employed to estimate the maximum sustainable yield. The estimated growth parameters; asymptotic length that the fish attains at an older age(L∞) and growth constant(k)of O. niloticus were 55 cm and 0.37 yr-1, respectively. Overall about 11 million O. niloticus populations were estimated to exist in the lake. The estimated current annual yield was 290.1 tons per year for O. niloticus fisheries of the lake. However, the predicted value of MSY was 313 tons per year obtained at fMSY of 136,249 nets. The length at first maturity (L50) was 39.6 and out of the total annual catch 93.1% were below their respective size of maturity. Thus, the current yield reduction might be due to growth overfishing with reduced mesh sizes. As reported in the earlier studies and according to the finding of this investigation, the catch and yield of Lake Chamo is in the state of reduction through year. Unless the lake is properly managed, the future yields of Lake Chamo will be declining that may lead the resources depletion. Co-management practices, using the recommended mesh size and level of effort (number of nets) should be considered for the sustainability of the resources.*

Keywords: Fish stock assessment, fish yield prediction model, Jones length based cohort analysis model

1. Introduction

Fish stock assessment may be described as the search for the exploitation level, which in the long run gives the maximum sustainable bio-economic yield from fishery (MacLean and Evans, 1981). Ethiopia has a remarkable diversity of lakes which differs considerably in size, shape, depth, permanency in stratification and biotic diversity (Yilma and Geheb, 2003; FAO, 2003).

The Ethiopian Rift Valley Lakes belong to a group of lakes formed by the East African Rift, running from north to south on the eastern side of the African continent. Most lakes are highly productive and well known for their aquatic diversity and indigenous populations of edible fish species (Tudorancea and Taylor, 2002; Ayenew and Legesse, 2007). Lake Chamo is one of the Rift Valley Lakes in Ethiopia and due to the combined effect of an increasing number of fishing nets and vessels; there has been a steady decline of fish landings in Lake Chamo (Ward and Wakayo, 2013).

O. niloticus is one of the edible fish species in Lake Chamo and are economically important as well as highly acceptable by the consumers in Ethiopia particularly in Rift Valley areas where fish production is very high. Nowadays, *O. nilotcus* is the most target fish species of Lake Chamo fisheries due to high demand in the market. The sustainable exploitation level was not determined for this important fish species. The aim of this study was searching for the optimum level of exploitation for *O. niloticus* stocks of Lake Chamo. The finding of this study would serve as an essential input for decision-makers in recommending proper fish resource utilization and management measures considering the potential of the lake in order to maximize the long-term benefits for fishermen and other societies.

2. Materials and Methods

2.1. Description of the study area

Lake Chamo is geographically located at 5°42'–5°58' N Latitude and 37°27'– 37°38' E Longitude and it is one of Ethiopian Rift Valley lakes with an area of 551 km^2 and a maximum depth of 16 m (Belay and Wood, 1982). The lake is located at an altitude of 1108 m and about 515 km south of the capital city Addis Ababa (Dadebo *et al.*, 2005). Lake Chamo is part of the Ethiopian Rift Valley Lakes Basin (ERVLB) in the Abaya–Chamo Drainage Sub-basin (ACB). The ERVLB comprises eight natural lakes and their tributaries. The ACB comprises Lake Chamo and Lake Abaya, and rivers and streams entering the lakes. The two lakes are connected via surface hydrology. Outflow from Lake Abaya enters Lake Chamo through River Kulfo, and an overflow from Lake Chamo through Metenafesha joins Sermale stream and subsequently the Segen River (Bekele, 2006).

The fishery on Lake Chamo is almost exclusively conducted with a surface gillnet, although long–lines are also used to some extent to African catfish (*Clarias gariepinus)* and *Bagrus docmak.* The nets are prepared locally by fishers themselves or by some other people involved in fishing gear making activity. Gillnets are the most important fishing gears and are typically set in the afternoon and hauled early in the morning. They are removed only to change the fishing ground or when maintenance is necessary. *Lates niloticus* is used to be the major target species. However, because of low catch rates, the fishing effort has been shifted to *O. niloticus* which may result to reduction of the stock of this fish species.

2.2. Methods of sampling and data collection

In Lake Chamo, there were five legal fishers' co-operatives who are landing their fish catches on 31 major landing sites. Of these, eight major landing sites (Bole, Ashewa, Gentafora, Bedena 1, Chika, Mehal, Wedeb and Girawa) were selected and used as sampling sites. The estimated total annual catch from 31 landing sites were obtained by multiplying the annual estimated catch from 8 landing sites by the fraction of **(**total estimated nets from 31 landing sites**)/(**total estimated nets from 8 sample landing**)** sites with the catch of respective length groups.

Sixteen data collectors (two from each landing sites) were trained to collect data from the commercial fish catches. The catch data were collected for ten months (February to November 2018). Data were collected from randomly selected boats in randomly selected 3 days in a week. During each day of sampling, the total lengths (TL) of randomly selected samples of *O. niloticus* was measured to the nearest 1mm by using a measuring board, sample weights and total weights of fish from each boat was measured to the nearest 1g and 100g, respectively by using electronic and hanging scale balances. Also sample nets and total number of nets deployed into the lake per day were recorded.

2.3 Data summarization and analysis

The catch statistics data was summarized in a manner useful for Jones length-based cohort analysis and length-based Thompson and Bell yield prediction model. The summarization and analysis were done by using Microsoft Office Excel (2010) software.

2.3.1. Estimating growth parameters

Asymptotic length (L∞) and growth rate (K) were computed by FAO-ICLARM Stock Assessment Tools (FISAT-II) software. These two growth parameters are important for mortality estimation and the third parameter (t_o) refer to theoretical age at length zero. An estimate of t_o be calculated using Pauly (1979) empirical equation:

$$\text{Log}(-t_o) = -0.3922 - 0.275*\log L\infty - 1.038*\log K \quad [1]$$

Where
t_o is the theoretical age at which fish would have at zero length.

2.3.2. Arrangement of length composition data

The length composition of catch data were summarized as a table of the average total annual catch distributed by length groups. This was done as follows:

- Length measurements recorded were grouped into 2 cm length intervals to prepare a table of the length frequency of *O. niloticus* sampled during the sampling occasions.
- Estimating the total number of fish caught during the un-sampled days of the year

was done by multiplying the average catch per day of the sampled 120 days of catch by the number of un-sampled days during the year.

Estimating the annual total length composition of fish landed

This was done by raising the length frequency of the sampled 120 days of catch by an appropriate raising factor which is equal to C/c, in which 'C'- the estimated total catch of fish during the whole twelve months and 'c'- the total catch of fish during the 120 days of sampling.

2.3.3 Estimating mortality parameters based on length composition data

For the estimation of total mortality rates, linearized length converted catch curve method was applied. Required input data was length structured catch data randomly sampled from the commercial fishery and the relative age of the fish that corresponds to the mid-length of the size groups, which was calculated by the following formula:

$$\Delta t = 1/k * Ln\ [(L\infty - L_1) / [(L\infty - L_2)] \quad [2]$$

$$t\ (L_1+L_2)/2 = -1/k\ \{Ln\ [(1-(L_1+L_2)\ /2/\ (L\infty)] \quad [3]$$

$$Ln\ \{[C\ (L_1, L2)]/\ [\Delta t\ (L_1, L2)]\} = a - Z*t\ (L_1+L_2)/2 \quad [4]$$

Where

Δt = is age interval between L_1 and L_2 or the time taken by L_1 to reach L_2

$t\ (L_1+L_2)/2$ = age of the average consecutive length groups (X variable)

$Ln\ \{[C\ (L_1, L2)]/\ [\Delta t\ (L_1, L2)]\}$ = Y variable

To obtain total mortality, regression analysis was conducted between X and Y variables.

Total mortality (Z) = fishing mortality (F) + natural mortality (M) [5]

The natural mortality coefficient (M) was estimated using Paul's (1980) empirical formula as follows:

$$Ln\ (M) = -0.00152 - 0.279*ln\ (L\infty) + 0.6543*\ ln\ (k) + 0.463*ln\ (T) \quad [6]$$

Where

M = is natural mortality coefficient

L∞ = asymptotic length

K = growth constant

T = mean annual surface water temperature of the lake

Then, the fishing mortality rate (F) was calculated by subtracting *M* from *Z*.

2.3.4. Estimating population sizes and fishing mortalities by length group (Jones, 1984)

Jones length-based cohort analysis model was used to estimate the population size and fishing mortality coefficient of *O. niloticus* by length groups. This was done in three steps as follows:

1. Estimating the population number of the largest length group in the catch. This was done as follows:

N (largest L) = C (Largest L)*(Z Largest L/F Largest L) [7]

Where

N (largest L) = the population of the largest length group in the catch

C (largest L) = the catch of the largest length group

Z (largest L) = the total mortality rate of the largest length group in the catch

F (largest L) = the fishing mortality rate of the largest length group in the catch

2. Estimating the population numbers of consecutively younger length groups in the catch.

This was done using the equation as follows:

$$N\ (L_1) = [N\ (L_2) * H\ (L_1, L2) + C\ (L_1, L2)] * H\ (L_1, L2) \quad [8]$$

Where

N (L1) = The population number of L1 (younger) fish

N (L2) = The population number of L2 (older) fish

H (L1, L2) = the fraction of N(L1) fish that survived natural death as it grows from length L1 to L2 and computed as the following equation (Jones, 1984).

$$H\ (L_1, L_2) = [(L\infty - L_1)/\ (L\infty - L_2)]^{(M/2K)} \quad [9]$$

Where

L∞= the asymptotic length (cm) of O. niloticus attained at mature size

L1 and L2= consecutive length groups of fish (cm) that contributed to the fishery

K = von Bertalanffy growth rate constant (yr-1)

M = the rate of natural mortality coefficient for *O. niloticus* stock of Lake Chamo.

3. Estimating the fishing mortality rate of the respective length groups

Fishing mortality values for each length group was estimated using the equation as follows.

$$F(L_1, L_2) = (1/\Delta t) * \ln [N(L_1)/N(L_2)] - M \quad [10]$$

Where
F (L1, L2) = Fishing mortality coefficient pertaining to the respective length group
N (L1), N (L2) and M are as defined above.

To know the status of the stock, the exploitation rate (E) was estimated from mortality parameters as: E = F/Z. The exploitation rate (E) equal to 0.5 is considered as optimum level of exploitation; whereas less than 0.5 refers to under exploitation and greater than 0.5 refers to overexploitation (Gulland, 1971).

2.3.5. Predicting maximum sustainable yield and optimum fishing efforts

Input data and parameters required were:

- Total number of fish caught per year structured by length groups
- Estimates of population number and fishing mortality coefficient (F) by length group (obtained from Jones length based cohort analysis)
- Values of the von Bertalanffy growth parameters (L∞ and K) and natural mortality coefficient (M)
- Mean weight of fish for each length group obtained as described above for cohort analysis

Thompson and Bell (1934) yield prediction procedure

Step 1: Estimating the total annual yield obtained under the current level of fishing

1. Estimating the yield obtained per year from each length group

Yield from each length group obtained per year Y (L_1, L2) - was catch in number per length group per year C (L_1, L2) multiplied by the average weight of each length group i.e.

$$Y(L_1, L_2) = C(L_1, L_2) * W(L_1, L_2) \quad 11]$$

Where
Y (L1, L2) = the yield (weight) of fish obtained per year from respective length group
C (L1, L2) = total annual catch of fish obtained from respective length group
W (L1, L2) = the mean weight of each length group estimated using equation

$$W(g) = a * L^b \quad [12]$$

Where
W (g) is the average weight of each length group, L = the average length (cm) of each length group i.e., L = (L1+L2)/2 in which L1 and L2 are the length intervals of consecutive length groups. 'a' and 'b' are values of the regression coefficients.

2. Estimating yield obtained from all length groups per year

The total estimated yield was obtained by adding up the contribution of each length group from the stock per year.

Step 2: Predicting yield obtained under different levels of fishing pressure

If the fishing pressure exerted on the stock changes, obviously the yield also changes (increases or decreases). Hence the yield obtained under different levels of fishing pressure was predicted by changing the current level of fishing pressure by a certain factor. In due regard the fishing level that gives the maximum yield is assumed to be optimum fishing level and is recommend to the management for sustainable fishing.

Step 3: Yield prediction under doubling of the fishing effort

Doubling the fishing effort also doubles the fishing mortality rate. Fishing mortality and fishing effort are related as follows:

$$F = q * f \quad [13]$$

Where
F = Fishing mortality,
Q = Catch-ability coefficient
f = Fishing effort

Procedures of predicting yield under the doubled F:

1. Calculating the changed fishing mortality

The new fishing mortality value under the changed F was calculated by multiplying the current F by the raising factor (X).

F (New) = F (current)* X [14]

Where

F (new) = the changed F

2. Calculating the changed total mortality rate under the changed F

Z (new) = F (new) +M [15]

Where

F (new) is the changed fishing mortality coefficient of each length group. M is the natural mortality coefficient estimated by equation 6 above.

3. Predicting the population number of fish under the changed fishing mortality

Since a change in fishing mortality obviously results in a change in population number of fish in the water, new estimates of population numbers in each length group need to be predicted under the changed fishing mortality condition. Thus, the population numbers under the changed fishing mortality were calculated from the following exponential decay relationship (Schnute, 1987; Sparre and Venema, 1992).

$$N(L_2) = N(L_1) * e^{-Z(new)*\Delta t(L_1, L2)} \quad [16]$$

Where,

$N(L_1)$ is the population number of length L_1 fish

$N(L_2)$ is the population number of length L_2 fish.

Also $\Delta t(L_1, L_2)$ is the time it takes for an average fish to grow from length L_1 to length L_2 and it is defined earlier by equation 2. Z (new) is the total mortality under the changed level of fishing and it is equal to the sum of the changed fishing mortality as defined above by equation 15.

4. Estimating the total death and catch in each length group under the changed fishing level

The total number of deaths expected while the fish grew from length L_1 to length L_2, i.e., $D(L_1, L_2)$ under the changed fishing level is equal to $N(L_1) - N(L_2)$. From this total death, the fraction died due to fishing make up the total catch. Accordingly, the catch per length interval corresponding to the changed fishing mortality [$C(L_1, L_2)$] was calculated from the following relationship (Wetherall *et al*., 1987).

$$C(L_1, L_2) = F(L_1, L2)/Z(L_1, L2) * D(L_1, L2) \quad [17]$$

Where

$F(L_1, L_2)$ and $Z(L_1, L_2)$ are the fishing and total mortality coefficients, respectively, under the changed level of fishing effort. Then, to estimate the expected yield obtained from respective length groups annually $Y(L_1, L_2)$ under the changed fishing mortality, the expected catch in number under the changed fishing level was multiplied by the mean weight of each length group as illustrated by equation 11. The total annual yield to be expected under the new level of fishing effort was then predicted by summing up the contributions of each length group.

Such predictions were evaluated for different values of fishing mortalities so as to see the full spectrum of the effect of changing fishing effort on the stock. According to the above analysis, the level of fishing mortality that gave maximum sustainable yield was considered as the biologically optimum level of fishing mortality. Since there is a one to one correspondence between fishing mortality (F) and fishing effort (f), the value of F-factor chosen as optimum was used to recommend how much the current level of fishing effort need to be increased or decreased to get the maximum sustainable yield from the stock (Sparre and Venema, 1992).

3. Results and Discussions

3.1 Status of Lake Chamo *O. niloticus* fishery

Overall, there were five fishers' co-operatives and 300 registered co-operative members of fishers operating in the lake during the time of sampling (Table 1). The fishing nets of Lake Chamo fishers are constructed and set differently considering the size of the target fish. These fishers own 60 boats and on average 207 nets which, were set daily in the lake. Each fisher on average owns 0.69 nets and about 3.45 nets were set per boat daily for the fishery. Overall, the total annual estimated nets were 75,555 during the year of investigation (365 days). The fishing activity takes place throughout the year and with this level of fishing effort, an estimated total number of 538,265 *O. niloticus* were caught during the year that weighed about 290.1 tons. The estimated average catch per net per day was 7 fish and it weighed about 3.84 kg/net/day.

Table 1: Catch statistics of *O. niloticus* fishery of Lake Chamo in 2018

Operation measurements	Value
Total number of fishers in operation	300
Average number of boats operated per day	60
Average nets set per day	207
Total number of nets set per year	75,555
Total number of fish caught per year	538,265
Total weight of catch (kg) per year	290,127
Catch per net (no./net/day)	7
Weight of catch per net (kg/net/day)	3.84

3.2 The length composition of sampled catch and estimated annual catch of *O. niloticus*

Totally 7,570 samples of *O. niloticus* were measured during the study period and the measured TL composition ranges from 15.0 cm to 53.4 cm with an average of 34.2 cm that composed the catch of the fishers during the time of sampling (Table 2). The maturity length (L_{50}) of *O. niloticus* was 39.6 cm as reported by Teferi (1997). The (L_{50}) here is too old but used due to the absence of recent study on the maturity length in Lake Chamo.

From the total of 7,570 *O. niloticus* measured, only 6.9% were above the L_{50} and 93.1% were below it, indicating that 93.1% of the caught fish were immature. As observed during the data collection, the main cause for catch of immature fish were the reduction of mesh sizes (11 cm) which was narrower than the recommended minimum mesh size of 18 cm (LFDP, 1997). Thus, a large numbers of *O. niloticus* were being removed before they grow and replace their populations. Out of the total estimated annual catch, over 95% of *O. niloticus* catch ranged in length between 19 to 41 cm and more importantly, the length groups' 25 to 37 cm total length composed about 63% of the total catch (Table 2).

Table 2: Sample catch and estimated total annual catch of *O. niloticus* by length group in 2018

Length group L1-L2	Total sample caught/120 days (number)	Estimated annual catch (number)	Proportion of length group composition from the total catch (%)
15-17	9	640	0.12
17-19	114	8106	1.51
19-21	569	40459	7.52
21-23	576	40956	7.6
23-25	586	41668	7.74
25-27	868	61719	11.46
27-29	872	62004	11.52
29-31	908	64563	11.99
31-33	713	50698	9.42
33-35	709	50413	9.37
35-37	668	47498	8.82
37-39	456	32424	6.01
39-41	271	19269	3.60
41-43	149	10595	1.96
43-45	63	4480	0.84
45-47	26	1849	0.34
47-49	8	569	0.1
49-51	3	213	0.04
51-53.4	2	142	0.03
Total	7,570	538,265	100

3.3 Growth and total mortality coefficient of O. niloticus

The estimated von Bertalanffy growth parameters for O. niloticus were $L\infty$ =55 cm, K=0.37 per year and t_o = -0.467 with the goodness of fit index (Rn) value of 0.203. The O. niloticus in Lake Chamo becomes liable to the fishing gears at the length of 15 cm and this length is the length at first recruitment (Tr) for O. niloticus of Lake Chamo (Tr = 15 cm) Table 3 (column 2, row 3). At a certain age (sayTr), the fish become liable to encounter the gears because they start migrating to the fishing grounds and this age is referred as the age of recruitment to the fishery (Sparre and Venema, 1992).

In Lake Chamo, O. niloticus started to be caught considerably at the length of 18 cm and 18 cm is the age at first capture (Tc).Because starting 18 cm in Lake Chamo are readily captured if they encounter the nets Table 3 (column 2, row 4). After the age of Tr, the vulnerability of the fish to the fishing net increases when they attain a certain age commonly referred as the age of first capture (Tc) (Schnute, 1987).

A length composition data prepared for a linear regression analysis was established between X and Y variables for total mortality estimation (Table 3).

Table 3: Length composition data of *O. niloticus* for length-based catch curve analysis in 2018

Length group	Catch			X	Y
L1-L2	C(L1,L2)	Δt (L1,L2)	(L1+L2)/2	t(L1+L2)/2	Ln(C(L1,L2)/Δt)
15-17	640	0.139	16	0.93	8.4
17-19	8106	0.146	18	1.07	10.9
19-21	40459	0.154	20	1.22	12.5
21-23	40956	0.164	22	1.38	12.4
23-25	41668	0.174	24	1.55	12.4
25-27	61719	0.186	26	1.73	12.7
27-29	62004	0.200	28	1.92	12.6
29-31	64563	0.216	30	2.13	12.6
31-33	50698	0.235	32	2.36	12.3
33-35	50413	0.258	34	2.60	12.2
35-37	47498	0.285	36	2.87	12.0
37-39	32424	0.318	38	3.17	11.5
39-41	19269	0.361	40	3.51	10.9
41-43	10595	0.417	42	3.90	10.1
43-45	4480	0.493	44	4.35	9.1
45-47	1849	0.603	46	4.89	8.0
47-49	569	0.778	48	5.57	6.6
49-51	213	1.096	50	6.48	5.3
51-53	142	1.873	52	7.86	4.3

Using the estimated von Bertalanffy growth parameters and the annual length-frequency data, the total catch curve was estimated by applying the length converted catch curve analysis (Figure 1).

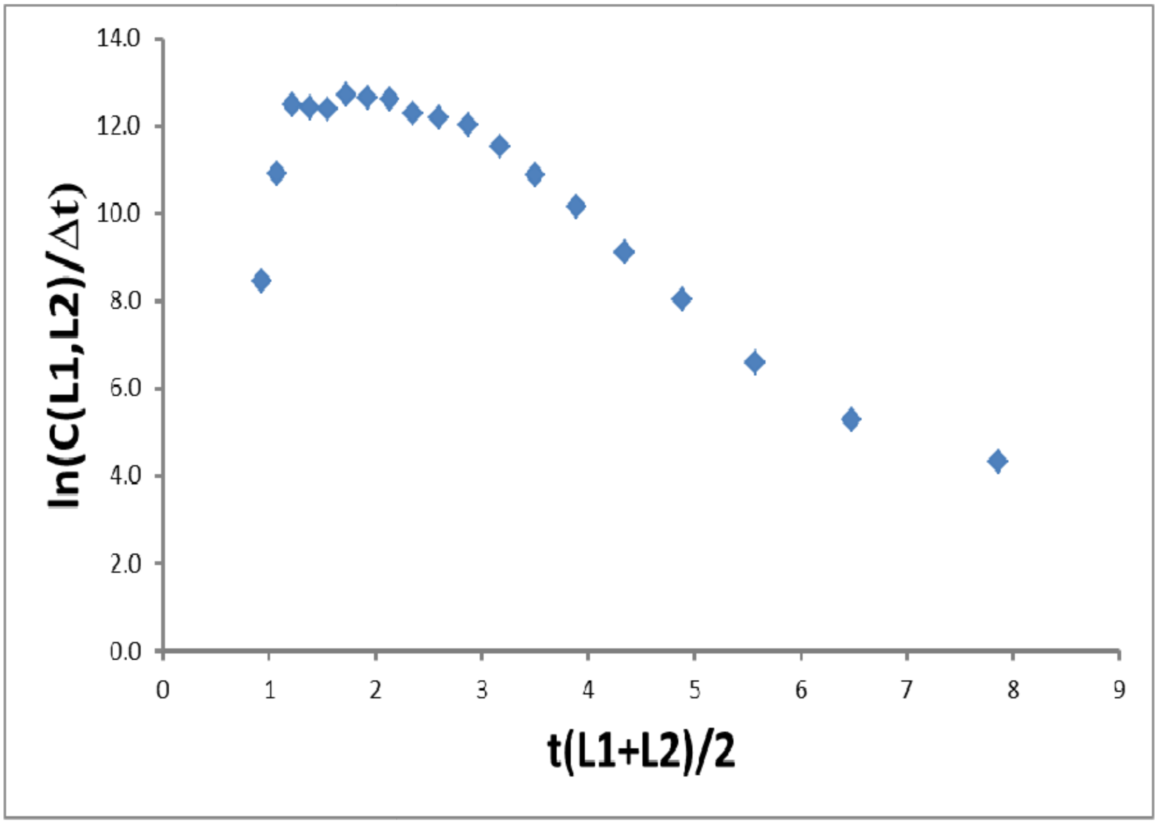

Figure 1: Length-based total catch curve of *O. niloticus* from Lake Chamo

For the total mortality (Z) estimation, the data points that did not fall on straight line were the data of the youngest age groups and were excluded as they had not yet attained the age of full exploitation (Figure 2). The slope of the regression line (b) was -1.5093 and hence, the total mortality rate (Z = 1.5093 yr^{-1}). Of the total mortality, natural mortality rate (M) and fishing mortality rate (F) was 0.79 yr^{-1} and 0.72 yr^{-1}, respectively. Using these mortality estimates, the exploitation rate (*E*) was (computed as 0.48) and indicates slightly under exploitation. The exploitation rate (*E*) equal to 0.5 is considered as an optimum level of exploitation; whereas less than 0.5 refers to under exploitation and greater than 0.5 refers to overexploitation (Gulland, 1971).

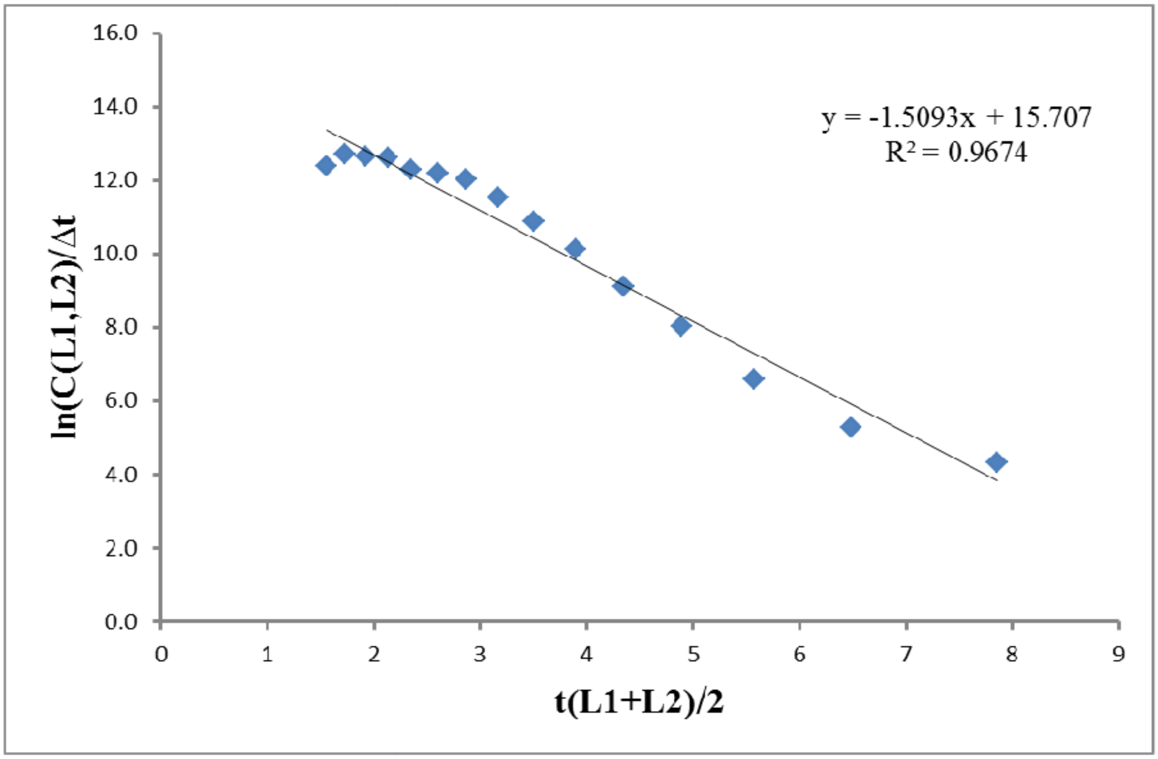

Figure 2: Linearized length-based catch curve of *O. niloticus* from Lake Chamo

3.4. Estimated population sizes and fishing mortalities

The estimated population number and fishing mortality coefficient by length group of *O. niloticus* are given in Table 4. The annual recruitment of *O. niloticus* in Lake Chamo was 1.92 million as indicated in Table 4 (column 9, row 3). Lake Chamo is known as the most productive lake in the country and its catch contribution is 29%, while Lake Hawassa contributes 7% (Tesfaye and Wolff, 2014). *O. niloticus* contributed on average more than 6600 tons annually for the country's fish supply, which is about 50% of the annual average catch for the period 1998-2010 (Tesfaye and Wolff, 2014).

According to Tekle-Giorgis *et al.* (2017), the annual recruitment of *O. niloticus* in Lake Hawassa is 3.95 million. This is about twice greater than the recruitment of *O. niloticus* in Lake Chamo, while the catch contribution of Lake Hawassa is very much less than Lake Chamo. This difference might be attributed to the difference in the fishing activities taking place on the lakes during the year and the number of nets as well as mesh size of the net that the fishers deployed in the two lakes.

Overall, about 11 million *O. niloticus* population were estimated to exist in the fished part of the lake as obtained by summing the population numbers of the respective length groups that composed the fishery given in Table 4 (column 9). This estimate belonged to the population of fish excluding the area of the lake protected for fish breeding. Even if it is said to be there is protected area for breeding, there was a problem of illegal fishing practices taking place in the area. As shown in Table 4 (column 9) the length groups' 29 to 47 cm fish shouldered heavy fishing mortality rate, bearing above 0.5 fishing mortality (F) per year. Although *O. niloticus* encountered the fishery ranging from 15 to 53.4 cm, most of the fishing pressure relied up on length groups starting from 27 cm to 49 cm.

Table 4: Estimated population, fishing mortalities and other parameters by length group *O. niloticus* in 2018

Length group	Catch				X	Y		
L1-L2	C (L1,L2)	F (L1,L2)	Δt (L1,L2)	(L1+L2) /2	T (L1+L2)/2	Ln(C(L1, L2) /Δt)	H(L1,L2)	N(L1)
15-17	640	0.003	0.139	16	0.93	8.4	1.06	1922271
17-19	8106	0.034	0.146	18	1.07	10.9	1.06	1723215
19-21	40459	0.185	0.154	20	1.22	12.5	1.06	1528583
21-23	40956	0.206	0.164	22	1.38	12.4	1.07	1315728
23-25	41668	0.233	0.174	24	1.55	12.4	1.07	1118336
25-27	61719	0.395	0.186	26	1.73	12.7	1.08	936150
27-29	62004	0.467	0.200	28	1.92	12.6	1.08	751168
29-31	64563	0.592	0.216	30	2.13	12.6	1.09	584441
31-33	50698	0.583	0.235	32	2.36	12.3	1.10	433753
33-35	50413	0.758	0.258	34	2.60	12.2	1.11	314329
35-37	47498	1.018	0.285	36	2.87	12.0	1.12	211156
37-39	32424	1.080	0.318	38	3.17	11.5	1.13	126342
39-41	19269	1.062	0.361	40	3.51	10.9	1.15	69763
41-43	10595	1.028	0.417	42	3.90	10.1	1.18	35812
43-45	4480	0.793	0.493	44	4.35	9.1	1.21	16817
45-47	1849	0.599	0.603	46	4.89	8.0	1.27	7726
47-49	569	0.337	0.778	48	5.57	6.6	1.36	3351
49-51	213	0.244	1.096	50	6.48	5.3	1.54	1399
51-53	142	0.36	1.873	52	7.86	4.3	2.09	453
Total (Million)								11

Note: The second column is the total number of fish caught per year in each length group estimated based on catch statistics record. Columns 3 and 4 are the time taken by (L1) to reach (L2) and mean length of fish respectively. Columns 5 and 6 are the established value of X and Y for regression analysis. Columns 7, 8 and 9 are natural mortality factors, estimated population numbers (N (L1)) and fishing mortality coefficients (F (L1, L2)), respectively.

3.5 Predicting maximum sustainable yield and optimum fishing efforts

3.5.1 Estimated total annual yield obtained under the current level of fishing

Table 5 below gives the estimated total annual yield of *O. niloticus*. Values in column 2 are the annual catch of the respective length group fish displayed in previous tables and they are shown here to illustrate the intermediary calculation steps. The current total yield (290.1 tons) pertaining to the respective length group (column 10) was obtained by multiplying the total catch of the respective length group by the corresponding mean weight values.

There was a drastic decline in the amount of catch over the period 1982-1991 (Dejene, 2008) and also the same situations were observed in this investigation. The drastic decline in catch level due to increased effort, even without a reduction in mesh size of nets, indicates the presence of recruitment overfishing (Cushing, 1982; Pauly, 1987; FAO, 1999; Israel and Banzon, 2000). According to Cushing (1982), recruitment overfishing causes a stock decline, which in turn results in the decline of catch.

However, in the current study, fishing effort was below effort of maximum sustainable yield (f_{MSY}), the decline in the catch is mainly related to growth overfishing with reduced mesh size. It is also important to consider that some natural mortality factors might be the reason as well as the mesh size reduction. Also, some other factors such as buffer zone agricultural practices, the application of monofilament nets and lack of political commitment for monitoring and evaluation could be some of the specific problems taken as a reason for the drastic decline in the amount of yield.

Table 5: Estimated total yield *O. niloticus* by length group under the current level of fishing of Lake Chamo in 2018

Length group	Catch				X	Y		Mean wt (kg)	Current Yield per year (kg)
L1-L2	C(L1,L2)	F(L1,L2)	Δt (L1,L2)	(L1+L2)/2	t(L1+L2)/2	Ln (C(L1,L2)/Δt)	N(L1)	W bar	Y(L1,L2)
15-17	640	0.003	0.139	16	0.93	8.4	1918330	0.072	46
17-19	8106	0.034	0.146	18	1.07	10.9	1719920	0.103	834
19-21	40459	0.185	0.154	20	1.22	12.5	1525869	0.142	5744
21-23	40956	0.206	0.164	22	1.38	12.4	1313530	0.190	7780
23-25	41668	0.234	0.174	24	1.55	12.4	1116589	0.248	10326
25-27	61719	0.395	0.186	26	1.73	12.7	934794	0.317	19535
27-29	62004	0.468	0.200	28	1.92	12.6	750142	0.397	24613
29-31	64563	0.593	0.216	30	2.13	12.6	583686	0.490	31645
31-33	50698	0.584	0.235	32	2.36	12.3	433217	0.597	30267
33-35	50413	0.759	0.258	34	2.60	12.2	313963	0.719	36223
35-37	47498	1.019	0.285	36	2.87	12.0	210917	0.856	40643
37-39	32424	1.081	0.318	38	3.17	11.5	126193	1.009	32729
39-41	19269	1.063	0.361	40	3.51	10.9	69674	1.181	22752
41-43	10595	1.030	0.417	42	3.90	10.1	35760	1.371	14521
43-45	4480	0.794	0.493	44	4.35	9.1	16789	1.580	7078
45-47	1849	0.600	0.603	46	4.89	8.0	7711	1.810	3346
47-49	569	0.338	0.778	48	5.57	6.6	3344	2.061	1173
49-51	213	0.244	1.096	50	6.48	5.3	1397	2.335	498
51-53	142	0.36	1.873	52	7.86	4.3	452	2.633	374
Total							11 million		290.1 (t/yr)

3.5.2 Predicted yield obtained under different levels of fishing pressure

The current fishing mortality rates of the respective length groups were considered as reference fishing mortalities and they were raised and lowered by certain factors (F-factors) to predict yield at the changed level of fishing mortalities. Table 6 shows results of predictions made under different fishing effort expanded on the *O. niloticus* stock of Lake Chamo. Thus, the new F-values are shown in Table 6 (column 3) are 1.8 times the value of the current fishing mortalities. The new F value here is the F-factor (1.8) at which the maximum sustainable yield (MSY) was obtained with its corresponding f_{MSY}. The rest of the columns had predicted values under the changed fishing mortality levels. The MSY for *O. niloticus* is 313 tons and its corresponding f_{MSY} is 136,249 nets (Figure 3). The current yield (290.1 tons) is below the MSY (313 tons) by 7.35%. The current effort (75,555 nets) is less than the f_{MSY}(136,249 nets), suggesting that the current level of effort need to be increased to f_{MSY} or it is possible to increase the current yield to the MSY by using the recommended mesh size and harvesting matured fish.

The maximum reported yield of Lake Chamo was 4,000 tons and the catch contribution of *O. niloticus* was 94% for the period of 1982-1991 (Dejene, 2008). *Oreochromis niloticus* catches have apparently declined from the recorded history of 60–80% contribution before 1998 to only about 50% in the period between 1998 and 2010, possibly due to the high fishing pressure on tilapia in some lakes (Tesfaye and Wolff, 2014). Although the *O. niloticus* production of Lake Chamo is highly reduced, the current the exploitation rate (*E*) was (computed as 0.48) which indicates the availability of a slight room to expand exploitation. Out of the total annual catch of *O. niloticus*, 93.1% were immature and thus, the reduction of yield is due to experiencing growth overfishing as well as some natural and anthropogenic factors under taking around the lake.

To avoid unexpected overfishing the target production of 2/3 f_{MSY} is always recommended and it allows a large fraction of the MSY to be harvested (80%) but reduces very much the risk of accidental over-exploitation and stock collapse (Doubleday, 1976).

Table 6: The length-based Thompson and Bell model output obtained under 1.8*current fishing pressure *O. niloticus* stock in Lake Chamo during 2018

Length group	Mean wt (kg)				Changed death	Expected catch	Expected yield
L1-L2	W bar	changed F	changed Z	changed N	D(L1,L2)	C(L1,L2)	yield (kg/yr)
15-17	0.072	0.005	0.79	1918330	198895	1152	83
17-19	0.103	0.062	0.85	1719435	200091	14567	1499
19-21	0.142	0.333	1.12	1519344	240993	71777	10190
21-23	0.190	0.372	1.16	1278352	220671	70886	13466
23-25	0.248	0.421	1.21	1057681	200627	70019	17353
25-27	0.317	0.711	1.50	857054	208667	99196	31397
27-29	0.397	0.842	1.63	648387	180300	93297	37036
29-31	0.490	1.068	1.85	468087	154560	89068	43656
31-33	0.597	1.051	1.84	313526	109952	62950	37582
33-35	0.719	1.367	2.15	203575	86624	55022	39535
35-37	0.856	1.834	2.62	116950	61472	43046	36833
37-39	1.009	1.946	2.73	55478	32218	22956	23172
39-41	1.181	1.914	2.70	23260	14477	10266	12121
41-43	1.371	1.854	2.64	8783	5858	4115	5640
43-45	1.580	1.429	2.21	2925	1943	1254	1981
45-47	1.810	1.081	1.87	983	664	384	696
47-49	2.061	0.608	1.39	319	211	92	190
4951	2.335	0.439	1.22	108	80	29	67
51-53	2.633	0.648	1.43	28	28	13	34
Total (t/year)							313

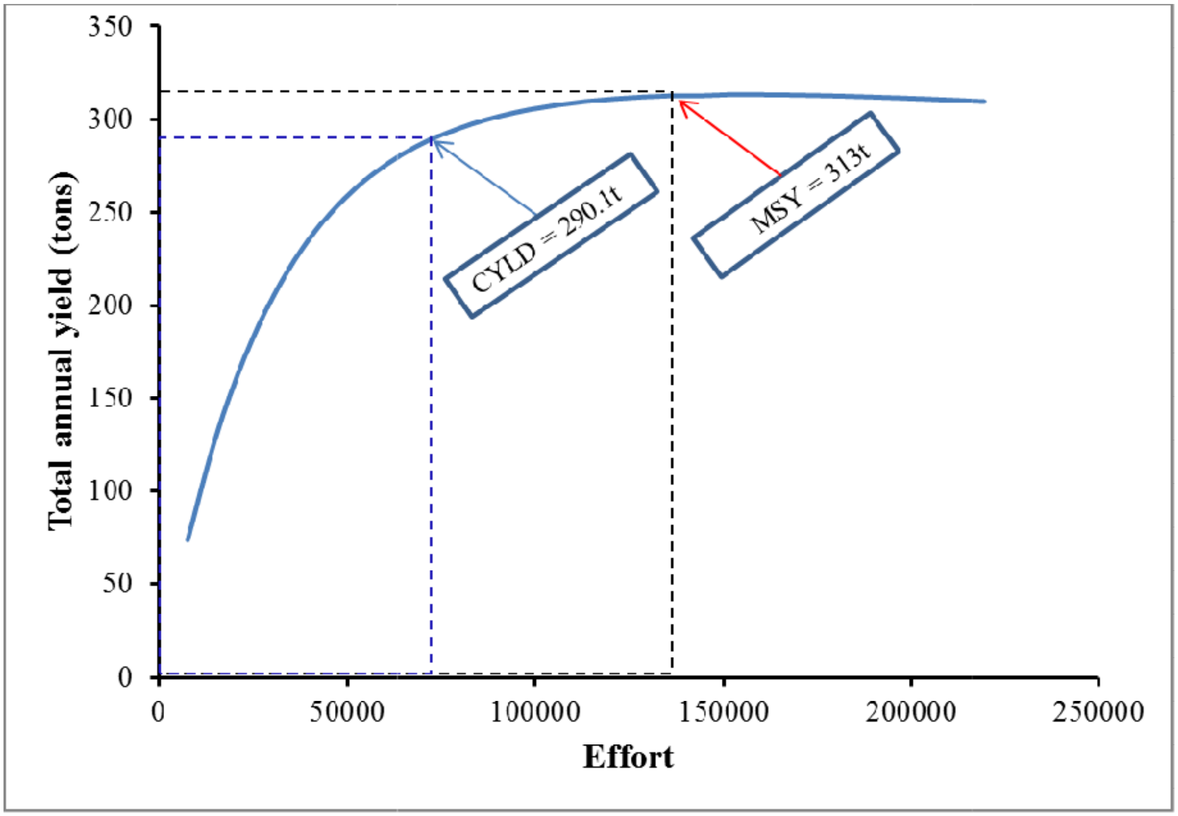

Figure 3: Maximum sustainable yield and fishing effort of *O. niloticus* in Lake Chamo

4. Conclusions and Recommendations

4.1 Conclusions

Fishers' of Lake Chamo are exploiting the fish with narrow mesh size nets. Consequently, the *O. niloticus* landed the catch were found to be highly dominated by fish whose sizes were below the L_{50} reported for this species. Thus, larger proportion of immature *O. niloticus* (93.1%) populations of Lake Chamo were exposed to heavy fishing pressure and hence, conclude that, the stocks are experiencing growth and recruitment overfishing.

The current yield (290.1 tons) is below the MSY (313 tons) and the reduction in yield is not due to overfishing but mainly related to growth overfishing with reduced mesh sizes. In summary, the future yield status of Lake Chamo is under the status of drastic reduction with the respective fish species in this study and the fish resource utilization of Lake Chamo calls for urgent management action for sustainable use.

4.2 Recommendations

Harvesting of immature fish with reduced mesh size is the major problem associated with reduced Nile Tilapia stock in Lake Chamo, which calls the use of recommended mesh size for sustainability of the resources. Therefore, management actions including multi-stakeholder participation in conservation and rehabilitation of fish resources for sustainable utilization of the natural resources in Lake Chamo are recommended. Moreover, the similar research activities for other fish species in the lake are also recommended for full information and conservation of the resources.

Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgements

I would like to express my deep gratitude to my late advisor Dr. Yosef Tekle-Giorgis for his invaluable support, patience, and guidance until his last breath, where this piece of work remembers you forever. I would also like to thank the Southern Agricultural Research Institute for funding this research.

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