

Land Degradation and Adaptive Mechanism in Northeastern Wollega, Ethiopia

Alemayehu Adugna



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Land degradation and adaptive mechanism in northeastern Wollega, Ethiopia

Alemayehu Adugna Urgessa

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This is to certify that the thesis prepared by Alemayehu Adugna Urgesa, entitled Land Degradation and Adaptive Mechanism in Northeastern Wollega, Ethiopia and submitted in fulfillment of the requirements for the degree of Doctor of Philosophy (PhD) in Geography and Environmental Studies (Natural Resource Management and Environment) complies with the regulations of the university and meets the accepted standards with respect to originality and quality.

Signed by the examining committee:

1. External Examiner: Dr. Leulseged Tamene Signature:_____ Date:_____
2. Internal Examiner: Dr. Amare Bantider Signature:_____ Date:_____
3. Spervisor : Dr. Assefa Abegaz Signature:_____ Date:_____
4. Chairman: Dr. Asmamaw Legas Signature:_____ Date:_____

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Abstract

Ethiopia is facing serious land degradation (particularly soil erosion, nutrient depletion and land-use/land cover changes) due to natural and anthropogenic influences. This thesis examines forms and drivers of land degradation and adaptive mechanisms in Northeastern Wollega, Ethiopia. The changes in land-use/land cover were assessed based on time series image processing (from 1972 to 2015). Soil samples were collected from three adjacent soil plots under different land uses (forestland, grazing land and cultivated land) at top and subsoil. Cross-sectional surveys of 200 household heads randomly were selected by two-stage sampling from five farming communities. The data were collected using structured questionnaires, key informant interviews and group discussions.

The studied land-use/land cover changes exhibited expansion of cropland and settlement at the expense of forest, shrub and grassland from 1972 to 2015. However, since 2005, shrubland and cropland experienced the highest gain and loss, respectively. These transitions were attributed to household size, productivity of cropland, total production of cereals, population growth, slope and agro climatic variations. The soil properties examined generally exhibited significant variations with respect to land-use/land cover changes and soil depths. Sand, silt, organic matter, total N, pH, CEC and Ca^{2+} content significantly decreased as forestland is converted into cropland/grassland/shrubland. Over all, cropland has the least concentration of soil physical and chemical properties.

Results from household survey showed that rural households adapted livelihood diversification in response to problems of land degradation. Livelihood diversification was significantly influenced by sex of household head, household size, farm size and land tenure regimes. Therefore, agricultural policies aimed at encouraging diversification will likely reduce the vulnerability of rural households to land degradation. Greater, diversification may be achieved through the spread and implementation of existing knowledge, income, technology and best practices.

Key words: *agriculture, sharecropping, cropland expansion, deforestation organic matter, cation exchange capacity*

Chapter 1

Introduction

Background of the study

Ethiopia covers an area of 1.13 million square km and is located between 3-15° N and 33-48° E. It is a large country endowed with varied topographical and climatic conditions. These made possible the presence of different faunal and floral resources. The vegetation types are highly diverse and occupied an estimated 2.4% of total land area. These had declined from that once covered more than 35% of the country's land mass (Eshetu, Giester & Hogberg, 2004). A mean annual rainfall of the country is over 1500 mm experiencing a seasonally wet and dry tropical highland climate type. This enhances mixed crop-livestock farming system, mainly in the highlands.

Ethiopia also has various soil types, of which 60 million hectares are agriculturally productive (Haile & Fetene, 2012). Agriculture supports 87.3% or over 23.6 million tons of total grain produced in the country (Bekele & Lars, 2003; Bewket, 2007). It is a key livelihood for over 85% of the population in Ethiopia (Beyene, 2015). Agriculture accounts for 43% of GDP, 83% of the labor force, 90% of export and 70% of the country's raw materials for large and medium scale industries (CSA, 2014). Cereals are produced on 10.14 million ha, which make up over 80.78% of total grains. Agriculture is mainly produced under small-scale holdings and is currently involving 12.6 million farmers (CSA, 2014). The average holding size of farmland is 1.2 hectares at national level. Because of the increase in human population, per capita land holding has reduced. This created pressure on the limited land for agricultural production and forced farmers to expand their farming to areas previously covered by vegetation.

Ethiopia's complex topography, geographical positions, rainfall, temperature and broad altitudinal variations contribute to the existence of a range of land-use/land cover (LULC) types (Hurni, 1988). LULC systems are dynamic because the direction and rate of changes are

controlled by a variety of practices (Mohammed, 2013). Population pressure with 2.3% of annual growth rate is potentially a significant driver of changes in LULC because rapid population growth accelerates competition for agricultural land (Beddington et al., 2012; Thomas et al., 2012; Tilman, Balzerb, Hill & Beforta, 2011). Conversion of forestland to cropland and grazing land largely occurs in the highlands for many years (Demeke, 2013; Mohammed, 2013). Changes in LULC lead to a significant change in soil physical, chemical and biological properties (Lemenih & Itanna, 2004; Fantaw, Ledin & Abdu, 2007). It reduces organic matter, cation exchange capacity and basic exchangeable cations, mainly through diminished litter production, bigger erosion rates and faster decomposition of organic matter by oxidation (Ermias, Shemelis, Laing & Fentahun, 2013). For that reason, numerous agricultural soil (particularly, total N and available P) in tropics are currently below their possible production levels (Fleskens & Stringer, 2014; Fleskens, Nainggolan & Stringer, 2014; Carreiras et al., 2014). The other factors for deficiency of soil are excessive grazing by livestock (Eshetu, Gieser & Hopberg, 2004), poor soil amendments in subsistence agriculture (Stringer & Dougil, 2013), cultivation of steep slopes without sufficient conservation measures (Jones, De Graaff, Duarte, Rodrigo & Poortinga, 2014) and lack of sustainable land management practices (Reed et al., 2011; Place, 2009). These have been recognized to be more serious problems in the soils of Ethiopian highlands where 25% of fertile lands are severely degraded (Bewket & Teferi, 2009; Haile & Fetene, 2012; Aweke, Singh & Lal, 2013).

In response to LULCC and subsequent soil deficiency, the country has implemented several soil and water conservation (SWC) measures since the early 1970s (Gebremichael et al., 2005; Tadele & Merrey, 2013). These measures had included construction of cutoff drains and contour bunds, restoration of gullies by grass planting and stone check bunds, establishment of

tree nurseries and demonstration woodlots and prohibition of activities such as tree cutting, grazing and cultivation in selected areas (Eshetu, 2014). SWC measures were done through government lead initiatives to achieve food security, enough household income and poverty reduction by reducing soil erosion and improving soil fertility (Kassie, Zikhali, Manjur & Edwards, 2009).

Initially, SWC efforts focused mostly on soil erosion control than increasing agricultural production (Bewket, 2007; Bewket & Teferi, 2009). Radical land reforms such as nationalizing all lands, redistributing of farm plots among families, reorganizing rural institutions, increasing assistance for agricultural growth, emphasizing on government-owned commercial farms, and collectivizing production systems among smallholders declared subsequent to the implementations of SWC (Deininger, Daniel, Holden & Zevenbergen, 2008). However, those achievements had been a failure and the outcomes were undesirable and unsustainable (Tesfaye, Negatu, Brouwer & Van Der Zaag, 2014). The reasons for the failure were the top-down approach pursued in the planning and implementation processes and unsuitable for their farming system circumstances (Wegayehu & Drake, 2003). It is argued that these failures prevent farmers from attaining goals of soil erosion control, poverty reduction, and increased agricultural production, which are critical incentives to increase land conservation by farmers (Shiferaw, Okello & Reddy, 2009). SWC were carried out without prior studies and externally introduced, which were alien and foreign to farmers. The main contribution of farmers in those conservation activities was labour, which was compulsory or based on food-for-work payments (Teklewold et al., 2013; Teshome, De Graaff, Ritsema & Kassie, 2014; Beyene, 2015).

As a result, revisions of approaches and policies have been made a few times to maximize conservation effects on land use and management system (Deininger et al., 2008;

Bewket, 2007; Deininger & Jin, 2006; Bekele & Drake, 2003). A series of policies and strategies have been put forward to rehabilitate degraded land and halt further degradation since 1991. The major strategies are Environmental Policy and Accompanying Conservation Strategy of Ethiopia (Belay, Van Rompaey, Poesen, Van Bruysee, Deckers & Amare, 2014), National Action Plan to Control Desertification (Kassie, Zikhali, Manjur & Edwards, 2009) and National Sustainable Land Management Framework (SLM) (Teklewold, Kassie, Shiferaw & Köhlin, 2013). These strategies and policies have been implemented to support the extension service in agriculture and livestock development of the present government. Consequently, new SWC strategies, approaches and technologies designed for farmers by technical experts (Mengistu, Bewket & Lal, 2015). Exclosures were installed at village level to keep livestock out of conserved areas (Belay et al., 2014). Wood collection and open grazing were completely banned from the conserved areas to protect natural areas and forests (Gebremichael et al., 2005). Alternative sources of wood and water reservoirs were provided to farmers. In addition, new farming systems such as the application of artificial fertilizers, drought-resistant and high-yield crop varieties were adopted to increase the productivity of agricultural practices (Pretty, Toulmin & Williams, 2011).

Simultaneously, farmers at household level adapt to land degradation by abandoning degraded cropland, moving into new land and diversifying livelihood. These measures and developments lead to a slowing down and eventually reversing of the ongoing land degradation in some parts of Ethiopia (Aweke et al., 2013; Tesfahunegn, 2015; Belay et al., 2014; Mengistu, Bewket & Lal, 2015). The main changes include forest transition, a change from net deforestation to net reforestation or greening of landscape (Mekonnen et al., 2015).

Concepts of land degradation

Land degradation is among of the world's greatest environmental challenge (Warren, 2002). UNCCD defines land degradation as “any reduction or loss in the biological or economic productive capacity of the land resource base. It is generally caused by human activities, exacerbated by natural processes, and often magnified by and closely intertwined with climate change and biodiversity loss” (UNCCD, 2014). This definition implies that land degradation is contextual and there have been no accurate measurement of the extent of degradation (Reynolds et al., 2011). Some studies consider land degradation as the outcome of the interplays between climatic vulnerability and land use changes (Neysen et al., 2004; Mekurai et al., 2012; Lanckrient et al., 2015). Others take a political ecology approach to identify chains of explanations that elucidate drivers and impacts of land degradation (Andersson, Brogaard & Olsson, 2011). Political ecology of land degradation adopts an integrated approach to study human and environmental systems. These systems are fundamentally interwoven and so are the options for livelihood support and ecological management (Reynolds et al., 2007).

Historically, the field of land degradation has been dominated by a linear cause-effect epistemology. This must be swapped with norms of complex adaptive system, such as heterogeneity, variability, self-organization and nonlinearity. Political ecology approach does take these norms and attributes land degradation to stakeholder interest, scale-specific socioeconomic and biophysical conditions (Warren, 2002). In this study, diversified biophysical and socioeconomic models were presented. These are combined to explore land managers' decisions and/or behavior concerning land use and management (Veldkamp & Lambin, 2001; Lambin et al., 2003). Biophysical models attributes to physiological characteristics of plant functional types (trees, shrubs and grasses) and nutrient cycling (decomposition and leaching).

The socioeconomic models of land degradation consist of entities such as demographics, human consumption, production, institutions, migration and resource extractions. These often consist of decision-making component (i.e., land and water use and management decisions) and a socioeconomic impact component (Lanckriet et al., 2015). Socioeconomic systems can be connected to environmental systems by articulating land-use/land-cover change (LULCC) as a function of multi-scale drivers and proximate factors driving land degradation. LULC model address location (i.e., identification of the natural and socioeconomic attributes), and the quantity and the rates of change (described in terms of LULCC). Finally, LUCC models often rely on land cover data derived from satellite imagery (Hill et al., 2008). Therefore, the aim of the present study is to explore potential drivers of land degradation and adaptive mechanisms to the problems of land degradation in the Northeastern Wollega, Ethiopia.

The main reason for choosing Northeastern Wollega was that the region was believed to have experienced high population pressure on natural resources and a high rural immigration. Northeastern Wollega has been experiencing rapid population growth since 1970s, caused by high birth rate and significant immigration of farmers from land scarce areas. These are believed to have contributed to increasing land degradation, which is a threat to smallholders. The main challenge for rural households in the study area, therefore, is reversing the ongoing land degradation while nourishing increasing number of population and changing diets. The fact that little or no empirical research has been carried out in the Northeastern Wollega on such a crucial issue encompassing all the aforementioned variables (drivers, types and impacts of LULCC, effects of LULCC on the variation of soil properties and existing adaptive strategies) makes the study pertinent and timely. In addition, this study is motivated by increasing need for knowledge on how human-environment and norms of complex adaptive systems are interwoven to reverse

and rehabilitate degraded land. By using critical realism as a combined ontological and epistemological approach, this study analyzed local dimensions of adaptation strategies that will mitigate adverse consequences of land degradation. Critical realist approach assumes that human societies transform their environment to survive and reproduce (Anderson, Brogaard & Olsson, 2011). Farm households practice a set of adaptation strategies to withstand the threats of land degradation. This may include new kinds of social relations and new ways of interaction with their environments.

Objectives of the study

The main objective of this study is to explore drivers of land degradation and rural households' responses to the impact of degradation in the Northeast Wollega, Ethiopia. The specific objectives of the study are to:

- (1) investigate changes in land-use and land-cover associated with changes in the population growth and other factors that has occurred since 1972
- (2) identify whether the change in land-cover is random or systematic
- (3) identify the effects of land-use/land-cover changes on the mean differences of soil properties
- (4) examine the effects of soil depth on some selected soil properties and identify the relationship between soil properties in top and sub soil layers.
- (5) examine how push and pull factors motivate diversification in response to land degradation within the local context

Description of the study area

Location

Northeastern Wollega covers an area of 14,979 hectares and is located between 9°50' and 10°10' N latitude, and 37°10' and 37°20' E longitude (Figure 1.1). This area is found in Jardaga-Jarte District within the Oromia Regional State and is part of the trap series of tertiary volcanic eruptions (Oromia Rural Land and Environmental Protection, 2013).

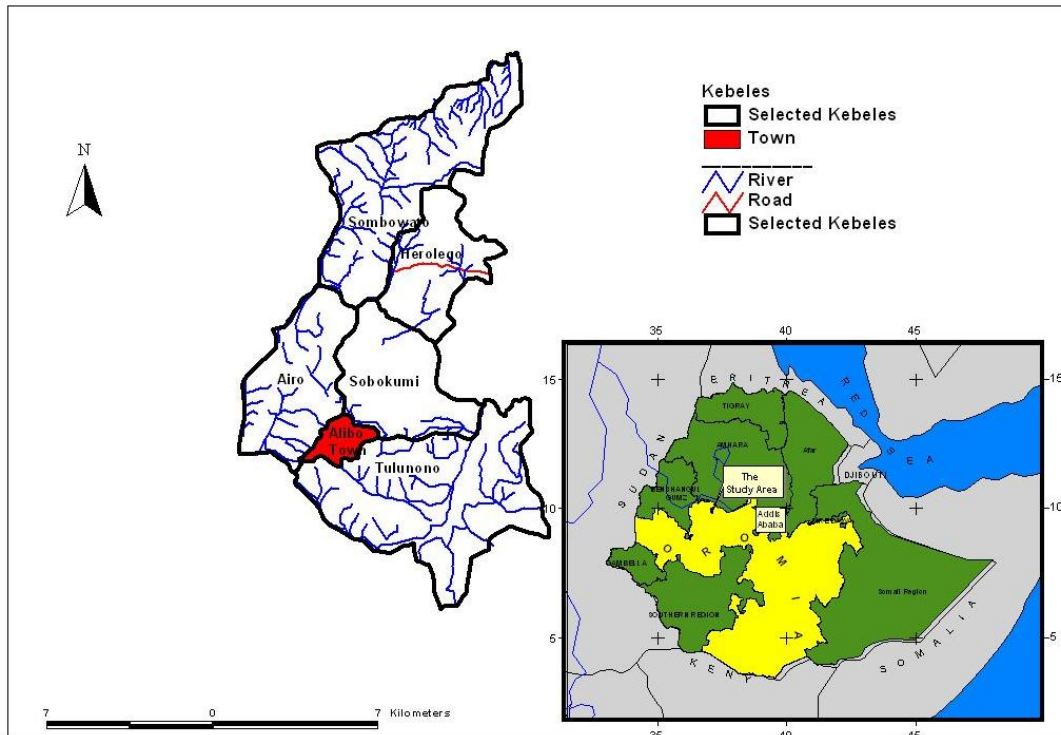


Figure 1.1. A map of Northeastern Wollega (Ethiopia) showing the location of the study area.

Climate

The climate types of the region are markedly influenced and controlled by altitude and regional/global weather systems. Meteorological records from a station within the study area (1979-2014) indicate that the mean total rainfall is 3495.65mm with a maximum of 5582.24mm in 1996 and a minimum of 1827.94mm in 2002. This results in high inter-annual variability of rainfall. The rainfall shows mono-modal pattern and more than 80% of which occurs between May and October (Figure 1.2). The highest rainfall occurs during August. Occasional rain also

falls during the dry months (January and February). Air temperature is also an important climatic element pertaining to LULCC, soil variability, agricultural activities and biodiversity. Generally, the mean annual temperature is 17.76 °c. The warmest month is April (20.18°c) while the coldest month is August (15.34°c) (Figure 1.2). This area forms part of Blue Nile (Abay) River basin.

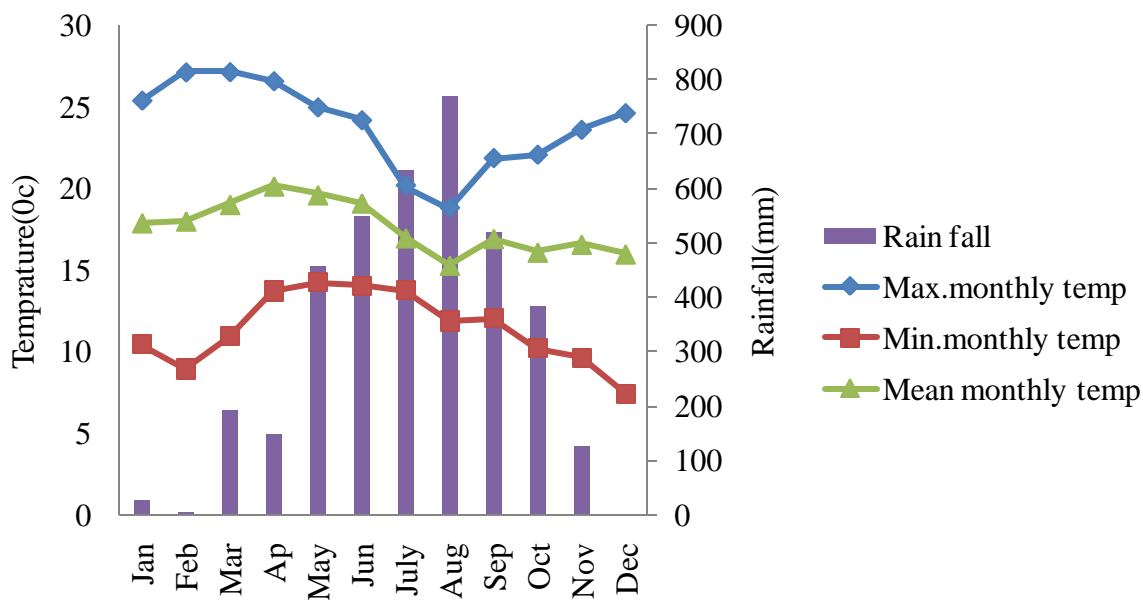


Figure 1.2 : Mean, maximum and minimum monthly temperature rainfall records of Northeastern Wollega, Ethiopia, (1979-2014) based on the records of Alibo town meteorological station (2414 masl)

Topography

Diverse slope gradient classes, slope aspects and slope forms (Figure 1.3), characterize the study area. According to classification system of FAO, which is derived from 90m resolution DEM using GIS spatial Analyst), about 32% of the study area constitute from flat to gently slope gradient (>5%), 25% from sloping to strongly sloping (5-15%) and 43% from moderately steep to very steep slope (>15%). The agro-climatic zones were classified into three main: (1) *Kolla* (humid tropical), a dry and a moist areas having <900 and 900-1400mm of annual rainfall, respectively. This zone accounts for 0.9% of Northeast Wollega’s land area. (2) *Weyna Dega*

(humid subtropical), the dry, moist and wet areas (having >1400mm annual rainfall) zones and accounts for 12.1% of the land area. (3) *The Dega* (humid temperate) with moist and wet zones but there exists no dry zone and accounts for 87.1% of the land area. Hurni (1990) in different areas of Ethiopia also used such classifications of agro-climatic zones. All zones are suitable for agricultural production. Soils developed from volcanic ashes and reworked materials from tertiary volcanic eruptions as well as sedimentation processes. Nitisols are the dominant soil type, mainly on undulating ground and steep slopes. Relatively flat river valleys have largely well developed Vertisols whereas Regosols and Cambisols are found on the steep slopes areas.

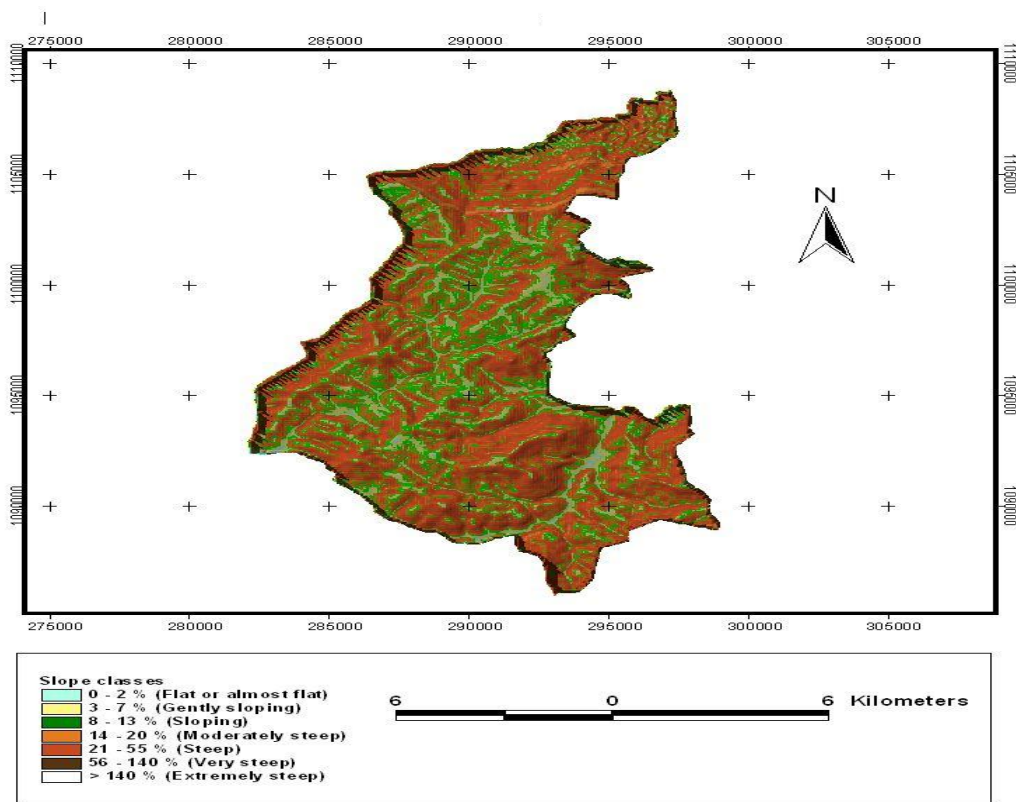


Figure 1.3: Slope classification of Northeastern Wollega, Ethiopia

Human population

Northeastern Wollega has an estimated population of about 58,339 people that reside in an estimated 9928 households. Based on household survey data, the average size of household for the study area is 7.1. This is higher than national (5.15) estimates. As can be seen from the distribution of household size by classes (Table 1.1), the size of households varies between 1 and 17. Some of 68% of the households have greater than three family size and this figure might be on the rise as population is increasing fast (159%). The population growth of the *district* is still high (3.7%) and is overwhelmingly rural (90%). Population growth is the result of the three elements of population dynamics-births, deaths and migration. Men, women and children aged of seven and above participate in various activities to sustain households. Division of labour is similar to the general pattern in sedentary agricultural areas of Ethiopia. Women do many more activities in everyday household assignments. Men are engaged in farming activities like land preparation, ploughing, planting /sowing, weeding, and harvesting.

Table 1.1: Persons and households by urban-rural residence and household size with percent distributions and averages in the northeastern Wollega, Ethiopia

HH Size	Urban + Rural				Urban				Rural			
	Persons	%	HH	%	Persons	%	HH	%	Persons	%	HH	%
1	879	1.8	879	8.9	189	4.0	189	15.7	690	1.6	690	7.9
2	2,160	4.4	1,080	10.9	448	9.5	224	18.6	1,712	3.9	856	9.8
3	3,651	7.5	1,217	12.3	552	11.7	184	15.3	3,099	7.0	1,033	11.8
4	5,480	11.2	1,370	13.8	668	14.2	167	13.9	4,812	10.9	1,203	13.8
5	6,770	13.9	1,354	13.6	705	15.0	141	11.7	6,065	13.7	1,213	13.9
6	7,614	15.6	1,269	12.8	744	15.8	124	10.3	6,870	15.6	1,145	13.1
7	7,231	14.8	1,033	10.4	511	10.9	73	6.1	6,720	15.2	960	11.0
8	8,752	17.9	1,094	11.0	568	12.1	71	5.9	8,184	18.5	1,023	11.7
9	2,781	5.7	309	3.1	117	2.5	13	1.1	2,664	6.0	296	3.4
10	1,640	3.4	164	1.7	70	1.5	7	0.6	1,570	3.6	157	1.8
11	891	1.8	81	0.8	44	0.9	4	0.3	847	1.9	77	0.9
12+	1,003	2.1	78	0.8	84	1.8	6	0.5	919	2.1	72	0.8
Total	48,852	100	9,928	100	4,700	100	1,203	100	44,152	100	8,725	100

Farming system

The basic means of subsistence is agriculture where land is used for multiple purposes such as cultivation of crops, animal pasture, forestry and construction. Cultivation of crops constitutes a major land use type in the district. Major cultivated crops include *teff* (*Eragrostis tef*, an Ethiopian cereal crop), *nueg*, barley (*Hordeum vulgare*) and maize grains. The major farming system of the area is cereal-livestock complex. Cereal mono cropping is common except around homesteads where potato and cabbages were intercropped with maize. Crop rotations that often follow the pattern of *tef*→*neug*→ wheat/barley→*tef* are the customary cropping system. The traditional oxen-drawn plough is used to prepare the fields for cultivation. Plowing was done repeatedly before sowing because farmers believe it controls weeds, and benefit crop yields. However, the frequency of plowing varied with crop types. The *tef* fields were plowed 6 to 7 times, whereas for other crops plowing took place only 3 to 4 times. The average productivity of *teff*, *nueg*, barley and maize is 1200, 600, 1700 and 4100 kg per hectare, respectively. Except for maize the average productivity of the crops were below the national average productivity. The national average productivity of maize was 3200 kg per hectare (CSA, 2014). Cultivation of cereal crops require finely tilled seedbed, the single cropping of the field, and down-slope final plowing to facilitate drainage, which can also drive land degradation.

Livestock tending

The major livestock of the study area constitute cattle, sheep, goats, donkey, mules and horses. Livestock number has increased by 93% between 2005 and 2013 with an annual rate of 10.4 % per year (Table 1.2). Farmers opt to have large number of livestock population because of its socio-economic importance. Livestock are valued as an important asset despite decreasing

grazing-land area. Cattle keepers are hired at every household heads to keep huge number of livestock on narrow grazing land. Sometimes, mainly during morning around homesteads, herding involves both children and hired keepers. Cattle herding has created job opportunity for the landless farmers. Those who have large holding size abandoned some degraded farmland to grazing land. On the other hand, small holders adapted to grazing shortage by adopting temporary herd-mobility during cropping season towards the peripheral area. They moved long distances from their home and stayed for at least three months with their cattle. This form of cattle keeping appeared challenging since cattle owners might be vulnerable to food shortage and cattle diseases. Furthermore, development agents (DA) assisted farmers, by supplying different species of grasses, to cultivate modern grass to ameliorate shortage of grazing land.

Table 1.2: Total number of livestock population between 2009 and 2013 in northeastern Wollega, Ethiopia (AoJW, 2013).

No.	Name	2009	2010	2011	2012	2013
1	Cattle	73,245	75,446	79,218	81,614	84,528
2	Sheep	8,698	8,895	9,339	9,619	11,667
3	Goat	9,763	10,061	10,564	10,880	18,383
4	Horse	668	686	722	743	793
5	Mule	877	904	949	977	1,174
6	Donkey	5,733	5,905	6,200	6,386	6,688
7	Hens	53,922	54,599	57,393	59,114	58,866
8	Dogs	1,500	2,513	2,680	3,780	7,689
9	Cuts	769	876	798	987	1350

However, livestock products mainly milks from cow and the capability of oxen to plow for long period are very low. The average amount of milk was half litter per day per cow. An ox serves for about 4 years in average. The traditional systems of keeping large herd of cattle and cropping patters that heavily relied on cattle population have been blamed for the low off-take from grazing land in the study area. The current price of livestock in the market was higher than

the previous one though farmers can't sell their livestock in large numbers. They could do that if there is cash demand (i.e. as fertilizer costs, education fees for numerous children and costs to cover social affairs), cattle getting old and the livestock owners do not have sufficient grain. Oxen are the principal resources, and means for crop production. A household head has two oxen in average. Oxen holding size is an important indicator of households' food security situations. A pair of oxen is needed to produce crops. A household head having only one pair of oxen or below could be categorized as poor farmer. Thus, oxen holding size affect household vulnerability to food insecurity and seasonal food shortage. The problem could be severe if the oxen face sudden illness, deaths and theft. Oxen-less households get their farms plowed through leasing out of their land for crop sharing, using ox pairing with others and exchanging human labor for oxen.

Study outline

This thesis is the result of a multi-perspective and multi-scale investigation on drivers and impacts of land degradation and adaptive mechanisms in northeastern Wollega. Several themes were covered by the study. The spatio-temporal changes in land-use/land-cover during the past five decades were investigated using remotely sensed images of the area, and the results are presented in chapter 2. The causes, impacts and implications of the observed dynamics in land-use/land-cover are also discussed in the same chapter. The random and systematic land-cover transitions were assessed in chapter 3. Detailed analysis of the various components of the transition matrix, gross loss, gross gain, persistence, swap, gain-to-loss ratio, net change-to-persistence, expected gain, expected loose and net change are explored in this chapter. The effect of land-use/land-cover changes on the mean differences of soil properties, specifically in soil physical and chemical properties were studied in chapter 4. Soil samples were collected from

forestland, grazing and cropland and analysed for variations in their physico-chemical properties. The need for site-specific approaches for land management is provided in this chapter. The effects of soil depth on some selected soil properties under different land use types are examined in chapter 5. In this chapter, the variability of soil parameters and the correlation among themselves with increasing soil depth under different land-use types was studied. In chapter 6, how “push” and “pull” factors interact to encourage, or otherwise, motivate diversification within local context are reported. This was done by examining the characteristics of rural household, determining whether livelihood is diversified, and identifying determinates of livelihood diversification. Chapter 7 presents a summary of the major conclusions of the study.

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Chapter 2

**Population growth and other factors affecting land-use and land cover changes in north-eastern
Wollega, Ethiopia**

Alemayehu Adugna^{1, 2*}, Assefa Abegaz¹, Asmamaw Legass¹, Diogenes L. Antille³

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Population Growth and Other Factors Affecting Land-use and Land-cover Changes in Northeastern Wollega, Ethiopia

Abstract

Land-use/land-cover changes in northeastern Wollega (Ethiopia) were investigated. This study provides a knowledge base that supports sound and informed decision-making on sustainable resource management in Ethiopia. The changes in land-use/land-cover observed in this region are linked to population growth, farming practice and tenure system. To quantify impacts, the study used a combination of land-use/land-cover detection techniques based on time series image processing (from 1972 to 2015), assessment of population dynamics and Pearson's correlation model. Results showed that since the 1970s, cropland and settlement areas expanded at the expense of land formerly occupied by forest, shrub and grassland. However, shrubland and cropland has increased and decreased, respectively, since 2005. Such changes were associated with a significant growth in the human and livestock population, poor farming system and tenure system. In order to sustain the necessary resource-base, appropriate population and land management policies need to be developed and implemented at national level but with local relevance. These policies may include population control, promotion of policies that support sustainable intensification of agriculture, and application of appropriate land management practices and diversification of the source of income for the rural communities.

Keywords: cropland expansion, deforestation, environmental protection, resource use efficiency, soil conservation.

Introduction

At the global-scale, changes in land-use/land-cover (LULCC) are reported to be significant over the past 25 years, particularly between 2000 and 2010 (Ningal, Harteminka & Bregt, 2008; FAO, 2012). The built-up environment represents approximately 2% of the land and estimates suggest that this area is set to increase, mainly at the expense of arable land (An, Liang & Liu, 2006). Agriculture uses approximately 30% of the total land area and has continued to expand at the expense of forestland, in particular in tropics (Lambin et al. 1999). On average, over the past 50 years, deforestation is reported to have progressed at a rate of 13 million hectare

per year (FAO, 2012). Despite this, changes in forestland cover have shown significant differences at regional level. For example, in North America it increased by 0.3 million hectare between 1990 and 2000 whereas in Europe, South America and Africa it showed a progressive decline during the same period of time (FAO, 2012). These changes are mainly driven by agricultural expansion and are expected to continue in the future (FAO, 2012).

Studies conducted in tropical regions using time series remotely sensed data showed that LULCC are linked to changes in the size of population and the rate of growth (Lambin, Geist & Lepers, 2003). Estimates suggest that the global population will increase from 6.8 billion, as recorded in 2009, to approximately 9.2 billion in 2050 (Godfray et al., 2010). Relatively less developed regions will contribute the largest portion to this fast growing global population (Goldewijk & Ramankutty, 2004). Meeting future demand for food and fiber will require that agricultural land is maintained and that productivity levels are not affected. There is also a requirement to minimize post-harvest losses including wastage during storage, transport and handling (Pfeffer, Schelhas, De Gioria & Gornez, 2005). Several studies (e.g., Lepers et al., 2005; Pfeffer et al., 2005; An et al., 2006; Deng, Huang & Rozelle, 2006) have indicated that drivers for LULCC differ between developed and developing countries. In developed countries, large-scale farming and urban development are recognized to be the main drivers for LULCC (Ramankutty, Foley & Olejniczak, 2002). However, in developing countries, particularly Sub-Saharan African countries, constrained yield increases, rapid population growth, changing diets and poverty are the main driving forces of LULC (Veldkamp & Lambin, 2001; Wood, Tappen & Hady, 2004).

Ethiopia is one of the developing countries where population has grown exponentially in the past few decades (Neyessen, Poesen, Moeyerson, Deckers, Mitiku & Lang, 2004). Since

1994, the population grew at an average of two million people per year representing a growth rate of 2.6% (Desse & Kleman, 2006). The majority of the population in Ethiopia lives in the highland areas (Neyessen et al., 2004). The population density is approximately 67 people per km² (Central Statistics Agency, 2012). Mixed farming is the main occupation of the rural population (Bahir, Ahmed & Antille, 2015). Subsistent rainfed agriculture is the source of livelihood for about 85% of the rural population (Central Statistics Agency, 2012). Farmers sustain their source of livelihood by converting natural woodlands into croplands. Expanding cultivated areas into forestlands does not appear to be a sustainable option and therefore efforts should be made to reduce the rate of deforestation (Moges & Holden, 2009).

Deforestation accelerates soil erosion, the loss of soil carbon and nutrients, natural habitats and impacts on biodiversity, and is therefore a matter of major concern for Ethiopia (Hurni, 2007). It is estimated that an area of approximately 1400 km² per year is converted from natural forest to other land uses (Woody Biomass Inventory and strategic Planning Project, 2004). Between 1990 and 2005 Ethiopia lost approximately 21,000 km² of forest and reduced to less than 3% of the total land occupied by forest in 1990 (Dessie & Kelman, 2006). However, there appears to be a paucity of information reported in the scientific literature about the relationship between population growth and LULCC in Ethiopia, particularly within the western regions of the country. Therefore, this study was undertaken to investigate this relationship and to provide background data that may be used by policy-makers to develop appropriate measures to address these issues. The Northeastern Wollega was chosen as the case-study area to investigate changes in land-use and land-cover associated with changes in the population growth and other factors that occurred since 1972.

Materials and methods

Land-use/land cover classification

Satellite images were used to classify LULC of the study area based on training sites (ground truthing), topographic maps, and in-situ observations. These preliminary investigations were conducted between December and February 2013. The nomenclature for the LULC types used in this study were based on those defined by the U.S. Geological Survey (1976), which provides sufficient detail and therefore fits well for the purpose of this work. Five LULC classes were identified, as follows: (1) forestland, (2) shrubland, (3) grassland, (4) cropland, and (5) settlements (Table 2.1).

Table 2.1: Description of land-use/land-cover classes in the Northeastern Wollega, Ethiopia.

LULC Classes	Description
Forestland	Areas covered with high, dense, trees forming closed or nearly closed canopy (70-100%). It includes under canopy trees mixed with short bushes and open areas. Dominant tree species are: <i>Juniperous procera</i> (Tid), <i>Podocarpus falcatus</i> (Zigba), <i>Olea europaea</i> (Woyera), <i>Rosa abyssinica</i> (Kega) and <i>Carissa edulis</i> (Agam).
Shrubland	Areas with >50% bush canopy mixed with some trees and <50% grass cover. Shrubs constitute non-herbaceous plants that branch out at the base of their stem and usually grow only to heights of <5 m.
Grassland	Grasslands are areas covered by grass that are used for communal grazing. Short grasses dominate the land cover. Formerly this land use was under forest cover. As informed by local elders, forest areas have evolved into permanent grass cover with continuous grazing.
Cropland	Cropland refers to area used for annual crop cultivation. It is a landscape dotted with Eucalyptus trees that are commonly found around homesteads. This land use has evolved with continuous clearing and plowing.
Settlement	In this study settlement refers to small towns and scattered rural villages that are with or without social services such as electricity, water, shops, schools, health centers and open markets.

Satellite imagery

The LULCC of the study area were investigated for four different years: 1972, 1986, 2005 and 2015. The reason for selecting 1972, as initial year of study, was that the satellite imagery of Ethiopia in general and northeastern Wollega in particular has released since the early 1970s. We select 1986 since it designates the period when the country hit by drought so that massive land-cover change was expected. We selected 2005 and 2015 to analyze the impact of land and water conservation practices of the current government and the recent status of land-cover in the study area, respectively. Landsat Multispectral Scanner (MSS), Landsat Thematic Mapper (TM), and Landsat Enhanced Thematic Mapper Plus (ETM+) were used as the major data sources. These data were used to produce three different LULC maps of the study area. Landsat imageries were downloaded using an Earth Science Data Interface from the Global Land Cover Facility. The imageries taken during the month of February (the driest month) were selected for this study as this ensured that sensors could be free from cloud murky. The spatial resolution of each Landsat pixel represents 80 m² of the Earth's surface.

The classification algorithms used to map the study area are a modified approach, which combines the unsupervised and supervised classification together to maximize the advantages of each. First, an unsupervised classification of the image was performed on the four image bands as determined from the data exploration analyses, using maximum likelihood with a first-pass parallelepiped algorithm. The signature statistics from this classification were saved and entered in to SPSS. Second, an unsupervised classification was performed with 20 iterations threshold. The statistics from the resulting signature file were added to those from the supervised classification, and a cluster analysis was performed using the squared Euclidean distance. A dendrogram was produced from the cluster analysis using a furthest distance method.

Subsequently, unsupervised clusters were labeled, classes that were not spectrally unique were merged, and poor training areas were deleted. This resulted into a training statistics signature file that contained 67 training areas. This signature file was used for the final supervised classification.

Sampling method and accuracy assessment

The number of samples (n) for each map classes was chosen by using the following equation from the multinomial distribution:

$$n = \frac{B\Pi_i(1-\Pi_i)}{b_i^2} \quad (2.1)$$

where: B is the upper $\left(\frac{\alpha}{k}\right) \times 100^{th}$ percentile of the X^2 distribution with one degree of freedom, $\Pi_i (i=1\dots k)$ is the proportion of the population in the i^{th} category, and b is the absolute precision of the sample.

This equation is calculated for each of ‘ k ’ categories and ‘ n ’ for all categories is subsequently selected proportionally to the size of the category. The analysis used a 95% confidence level, which was considered appropriate based on related studies (Congalton & Green, 1999), and the absolute precision was set at 0.05. The value for ‘ B ’ was obtained from a chi-square table, where $X^2_{(1, 0.01)} = 6.63$. For the study site, ‘ n ’ from the smallest class was chosen as the desired sample size to match Congalton & Green (1999)’s rule of thumb of a minimum of 50 samples.

A polygon of homogenous map class was selected as a sample unit instead of single pixel and cluster of pixels in an effort to minimize miss-registration issues and to better match the reference data based on image segmentation and object-based image analysis. To minimize sampling error, sample polygons that were unidentifiable, or contained more than one LULC

class, were deleted and new sample polygons were delineated using GPS for that location. Stratified random sampling methods were used to collect an optimum number of sample reference polygons for the classification accuracy assessment. The population (sampling frame), LULC, embraces distinct categories (separate strata): forestland, shrubland, grassland, cropland and settlement. Each stratum is then sampled as an independent sub-population, from which individual elements can be randomly selected (Table 2.2). There are several potential benefits to stratified sampling, including: (1) dividing the LULC into distinct, independent strata, enables inferences to be drawn about specific classes that may be lost in generalized random sampling; (2) utilizing a stratified sampling method can lead to more robust statistical estimates provided each class is proportional to its size in LULC; (3) data are more readily available for individual classes of LULC; (4) a simple, random sampling approach can be easily applied to different classes of LULC because each class is treated independently.

Table 2.2: Sample size, producer’s and user’s accuracy assessment of land-use/land-cover classification in Northeastern Wollega, Ethiopia

No.	LULCC	Sample size (n)	Producer’s accuracy (%)	User’s accuracy (%)
1	Forestland	483	79.4	71.1
2	Shrubland	50*	71.4	68.2
3	Grassland	239	70.2	73.9
4	Cropland	620	76.6	84.1
5	Settlement	70	86.0	84.2

*For shrubland, 50 sample sizes were chosen as the desired sample size close to Congalton & Green’s (1999) rule-of-thumb of a minimum of 50 samples per class. Using Equation 1, the value was small to be considered for this study.

Site-specific accuracy assessments were performed using an independent dataset to assess classification accuracy. This approach was chosen because it represents the classification accuracy of remotely sensed data in the form of an error matrix (Table 2.3). An error matrix is a

square array of numbers positioned in rows and columns, which express the number of sample units (referred to in this study as ‘polygons’) assigned to a particular category relative to the actual category as verified on the ground. The columns usually stand for the reference data while the rows stand for the classification generated from the remotely sensed data. Error matrix is also important as it enables series of descriptive and analytical statistical techniques to be generated. Overall accuracy (Table 2.3) is one among the statistical descriptive computed from error matrix. This is computed by dividing the total correct, that is, the sum of the major diagonal by the total number of pixels in the error matrix. The overall accuracy of this study was 76.7% in 2005.

Table 2.3: An error matrix of land-use/land-cover classification in Northeastern Wollega, Ethiopia

		Reference Data					Row total
		Forestland	Shrubland	Grassland	Cropland	Settlement land	
Correct map categories	Forestland	81	6	10	9	8	114
	Shrubland	11	45	8	0	2	66
	Grassland	6	11	85	12	1	115
	Cropland	0	1	15	95	2	113
	Settlement land	4	0	3	8	80	95
	Column total	102	63	121	124	93	503

Producer’s accuracy (measure of omission error) was computed by dividing the total number of correct pixels in a category by the total number of pixels of that category as derived from the reference data (the column total). This procedure illustrates how well a certain area can be classified or indicates the probability of a reference pixel being correctly classified (Table 2.2). The user’s accuracy, that is, a measure of commission error is computed by dividing the

total number of correct pixels in a category by the total number of pixels that were classified in that category (the row total). This procedure is a measure of reliability, which indicates the probability that a pixel classified on the map/image actually represents that category on the ground (Table 2.2). While the areas of each LULC for 1972, 1986, 2005 and 2015 were computed from Landsat images, the corresponding areas for each LULC between-years were calculated by multiplying the area of individual LULC by the annual rate of change. This latter measure was obtained using Equation 2.2.

$$r = \frac{\frac{L_2 - L_1}{L_1} * 100}{t} \quad (2.2)$$

where: r is the mean annual rate of LULCC for the a given study period, L_2 and L_1 are LULC area (ha) of 1972 and 2015, respectively and ' t ' is the interval year between 1972 and 2015 (43 years).

Population size

In Ethiopia, the first national population census was carried in 1984 and since then, a census has been conducted every ten years (in 1994 and 2007). Pre-and inter-censuses periods of population of the study area were estimated using Equation 2.3:

$$P_o \pm t = P_o(1 + G_r \times t) \quad (2.3)$$

$$G_r = (R_b - R_d) + (I_m - O_m) \quad (2.4)$$

where: $P_o + t$ is total population estimated from the previous census year to the ' t ' next year, P_o is the total population at the census year, G_r is growth rate, R_b is the birth rate at the census date, R_d is death rate at the census date, I_m is inward migration rate, O_m is outward migration rate and t is the number of years after the census date.

This study has used Pearson's correlation to analyse the association between LULC types and population growth.

Other factors

Other factors affecting LULC considered in this study include a rising number of livestock population, poor farming system, land tenure system, limited access to agricultural inputs and absence of credit supply. These data were collected via secondary sources from agriculture and rural development office and CSA as well as key informant interview.

Results and discussion

Changes in land-use/land-cover since 1972

The results of the LULC classification for the time series (1972-2015) are presented in figure 2.1. Shrinkage of formerly natural lands such as forest, shrubland (pre-2005) and grassland, denote the concurrent expansion of agriculture. Clearance of forest is mainly for conversion of that land to cropping but also to provide a source of fuel such as wood and charcoal. Between 1972 and 2015, the areal extent of forestland was decreased by 1.77% per year (Table 2.4). The areal extent of grassland was increased in the first period (1972-1986). However, the decrease observed in the area occupied by grassland between 1986 and 2015 may be attributed to changes in use and management of grazing lands. The use of grazing land shifted from communal to private in the 1990s. In the late 1990s and early 2000s, all demands for livestock fodder were geared towards private grazing land. The shift to private grazing land also induced overgrazing and accelerated deforestation as livestock population increased by more than 90% between 2005 and 2013 (Department of Agriculture, 2013). Areas that had been utilized exhaustively were subsequently taken out of production (closure) when these

conservation programs were implemented. This process resulted in widespread degradation of soil resources and encouraged the establishment of land and water conservation programs (Ouedraogo, Runge, Eisenberg, Barron & Sawadogo, 2014).

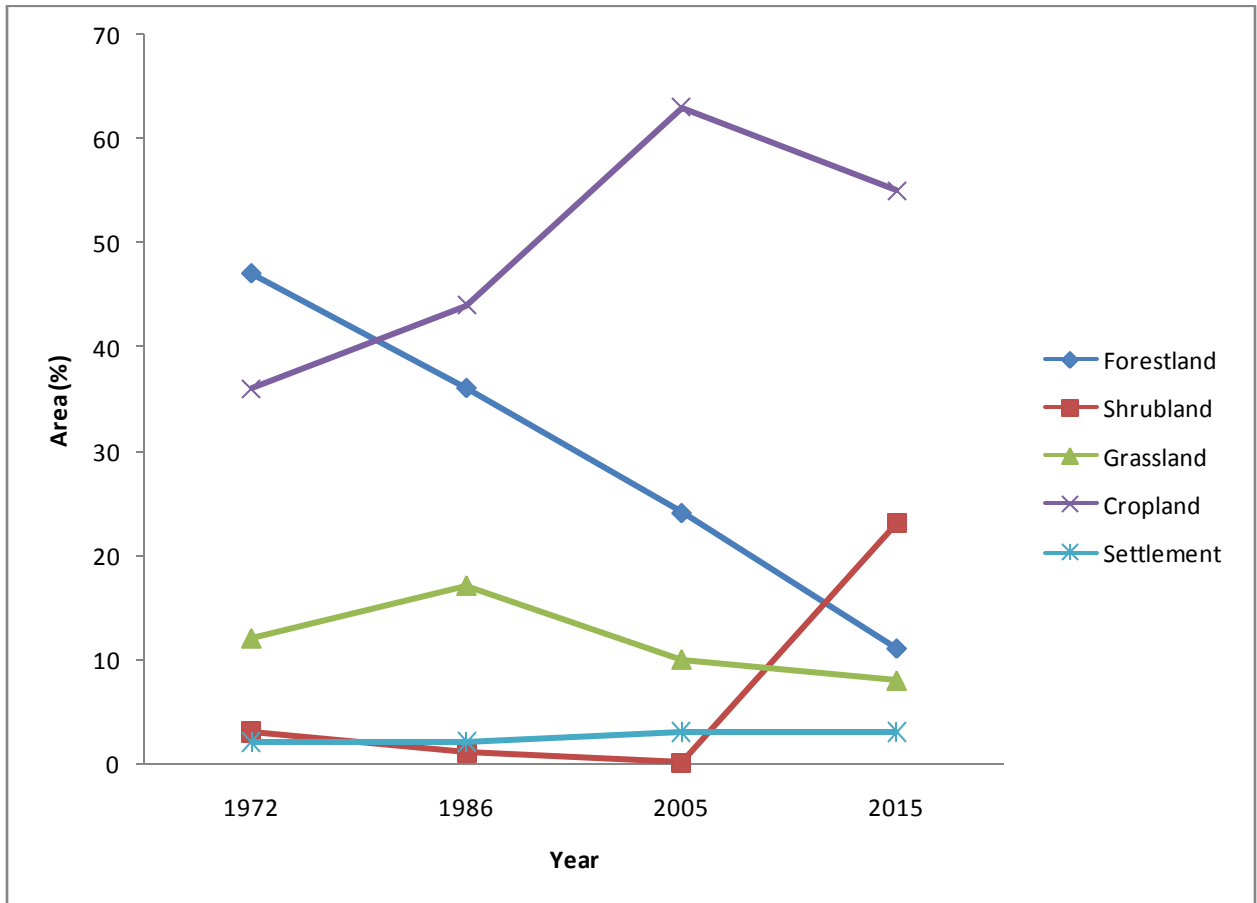


Figure 2.1: Areal extent of land-use/land-cover types of Northeastern Wollega, Ethiopia (1972-2015)

Figure 2.1 shows the increase for land that has been brought into cropland between 1972 (5,444 hectares) and 2005 (9,414 hectares), representing an increase of 73% (Table 2.4). The rate of change in cropped areas was relatively higher in the second period (2.2% per year) compared with the first period (1.6% per year). This is in close agreement with those reported in Lambin et al. (2003). This latter study attributes expansion of cropland at the expense of forest, savannah,

and stepper lands in response to the need to meet the demand for food and fiber of local communities.

Table 2.4: Trends of land-use/land-cover change observed in different periods in Northeastern Wollega, Ethiopia

LULC category	1972-1986		1986-2005		2005-2015		1972-2015	
	Change (ha)	Rate of Change (% per year)	Change (ha)	Rate of Change (% per year)	Change (ha)	Rate of Change (% per year)	Change (ha)	Rate of Change (% per year)
Forestland	-1,652.3	-1.7	-1,705	-1.7	-2471	-6.8	-5329	-1.77
Shrubland	-317.3	-4.8	-138	-4.7	+3355	+2097	+2900	+14.3
Grassland	+719.3	+2.8	-1,045	-2.2	-258	-1.7	-584	-0.74
Cropland	+1,185	+1.6	+2,786	+2.2	-1145	-1.2	+2825	+1.21
Settlement	+65.6	+2	+103.3	+1.8	+19	+0.46	+188	+1.9

Note: plus (+) refers to gains from other LULC while minus (-) indicates loss of land use/land cover to other uses/cover.

However, since 2005, shrubland and cropland has increased and decreased, respectively (Figure 2.1). Rapid expansion of shrubland and declining of cropland imply for reversal of the direction of LULCC. These changes were also reported elsewhere by recent studies (Braimoh, 2006; Versace, Ierodionou, Stagnitti & Hamilton, 2008; Barbier, Burgess & Grainger, 2010; Díaz, Nahuelhual, Echeverría & Marín, 2011; Teixeira et al., 2014; Oudraogo, Barron, Tumbo & Kahimba, 2015). Degraded agriculture lands were abandoned and replaced by plantations (Figure 2.3). Plantations include combinations of trees, fodder, crops and shrubs aimed at controlling the run-off and soil erosion (Figure 2.4).

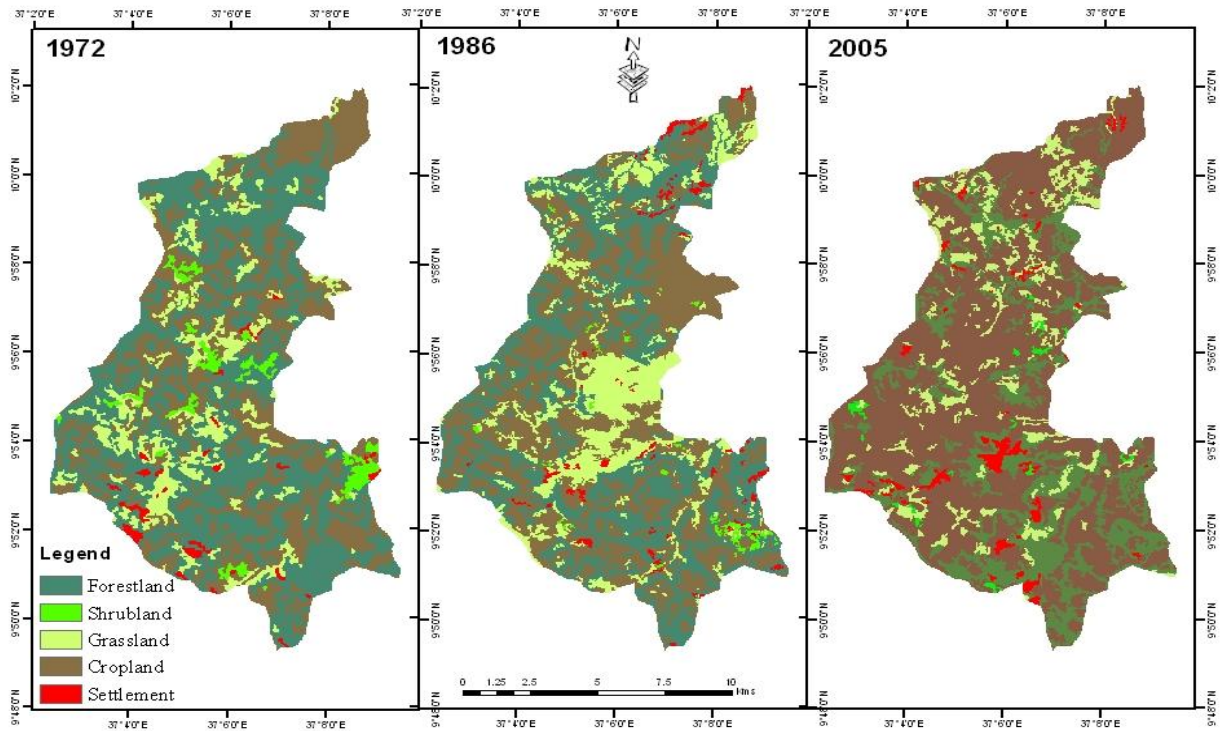


Figure 2.2: Land-use/land-cover maps of Northeastern Wollega, Ethiopia

As shown in figure 2.4, the re-growth (plantations) are grown in protected areas (area closure). This shows that farmers are using abandoned agricultural land as both conservation sites and sources of additional income. People use to sell grasses produced on abandoned land to the households with grass-scarce.



Figure 2.3: Abandoned agricultural land in Northeastern Wollega, Ethiopia



Figure 2.4: Evidences of re-growth in Northeastern Wollega, Ethiopia

Drivers of LULCC

Population growth

The population of the study area was 25,281 in 1984, 33,730 in 1994 and 48,943 in 2007. The population of the study area was estimated to be 19,942 in 1972 and 58,339 in 2014, which results in an average growth rate of approximately 3%, slightly above the national average (2.6%). These changes in population are attributed to several factors, including: (1) migration of farmers from Horo, Agamsa and Bure, respectively to adjacent areas, which at present are overpopulated, (2) declining of soil fertility, land fragmentation and frequency of draught, (3) continuous shrinkage of suitable land for subsistence crops such as maize, wheat, *teff* and barley, and (4) the influence of high fertility rate among the population as well as low mortality rate, and early marriage of women coupled with a culture of early child bearing and large family size.

Results derived from Pearson's correlation analyses indicate that changes in LULC are significantly correlated with population growth (Table 2.5). There were strong relationships between population growth and LULCC in cropland ($R^2 = .99$), forestland ($R^2 = .94$), shrubland

($R^2 = .81$) and settlement areas ($R^2 = .98$). However, population growth and changes in area of grassland were not correlated ($R^2 = .40$). A significant relationship between population growth and areas of cropland suggest lack of technological development and dominance of slash/burn systems in the study area. This continuous expansion of cropland was attributed to the rapid population growth and high agricultural potential of highlands due to reliable rainfall and relatively fertile volcanic soils. From population and LULC data, however, arable land per capita declined from 0.27 hectares per person, as recorded in 1972, to approximately 0.20 hectares per person in 2005. Consequently, available land used for agricultural production appears to be insufficient and may lead to shortages of food and increased cultivation on steeper slopes with the acceleration risk of soil erosion. Several other studies conducted in tropical regions (Pahari, Umezaki & Ohtsuka, 2001; Kok, 2004; Wood et al., 2004; Pfeffer et al., 2005) have also shown similar results.

The National Population Policy (NPP), introduced by the Ethiopian government in 1993, aims to harmonize the imbalanced relationship between population growth and LULCC (resource demand). The policy is based on the assumption that population problems may be aggravated by spatial mal-distribution, youthful age structure, high fertility rate, and the disadvantaged position of women in the society. Specifically, this policy was designed to raise the contraceptive prevalence rate among the currently married women by 44% in the year 2015 to control population growth. Reaching this goal, however, is a remote possibility since contraceptive prevalence rate was 23% in rural areas, where 85% of the country's populations reside in 2011 (CSA & ICF, 2012). Even though it was a major step forward, the NPP missed specific and measurable objectives, and guidelines for the concrete implementation of fertility reduction policies and family planning service delivery. The rationale of the policy should have

been designed to change the attitude and practice of rural population towards child bearing and tenure of natural resources, respectively. Controlling ultimate size of the population merits concern than balancing spatial distribution of population. It seemed that cropland expansion through the conversion of forests for subsistence endures as long as population number remains ever increasing. This could be persisting due to lack of modern production techniques and financial capital to access farm inputs. This finding supports the view of Lambin et al. (2003), Ouedraogo, Tigabu, Savadogo, Compaoré, Odén & Ouadba (2010), and Aklile and Beyene (2014) who recognized population growth as one of the main drivers for LULCC via the demand for additional farmland in tropical regions.

Table 2.5: Results of Pearson’s correlation between population growth and land-use/land-cover types

Land-use/land-cover	R ²
Forestland	0.943**
Shrubland	0.812*
Grassland	0.402 ^{NS}
Cropland	0.994**
Settlement	0.980**

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

NS. Correlation is not significant at the 0.05 level (2-tailed).

Other factors

Other factors include a rising number of livestock, poor farming system and land tenure system, limited access to agricultural inputs and credit. Livestock number in the study area has

increased during the study period. Vegetation cover declines under heavy stocking rates. Animal hooves on limited grazing land demolish vegetation cover. Footpaths used by humans and cattle develop into rills and the gullies. These can cause LULCC and land degradation (Lambin et al., 2003). Cropping and livestock rearing are the common farming system and dominant source of livelihood of the local community. People rely largely on practices suited to small-scale farming as a means for food and income. Most of the arable land is covered with *teff*, maize, barley and wheat, which require extensive land. The production of these crops also expose the soil to erosion and leaves the soil bare during the early growing season and after harvest. As land is being intensively used for crop production and soil is exposed to erosion, the area of degraded land is expanded. Thus, farmers will have additional cultivated land by removing vegetation (Meshesha, Tsunekawa & Tsubo, 2011).

Government policies promoting the expansion of agriculture to increase agricultural production as well as changes in the land tenure system are the main contributing factors to LULCC observed within the study region. Land use policy protects farmland, forests, water quality, open space and wildlife habitat. Conversely, uncontrolled development will destroy the natural environment and long-term economic growth. Ethiopia has experienced several changes in land ownership system. The reform act of 1975 removed private land ownership and nationalized all rural lands. Federal Democratic Republic of Ethiopia land policy (1995) adopted a public ownership of rural and urban land. According to respondents, these changes have been the sources of uncertainty among farmers and rural communities about the tenure security and land rights. The majority from the group discussion stated that their motivation to take care of their land and practice land management practices is affected by tenure security. These affect land degradation through their impacts on farmers' decisions with respect to land use and land

management practices (Lambin et al., 2003; Campbell, Lusch, Smucker & Wangui, 2005; Lepers et al., 2005; Ningal et al., 2008; Aklile & Beyene, 2014).

Impacts of LULCC

The impact of LULCC are manifest most clearly as land fragmentation, changing patterns of vegetation cover, particularly deforestation in Northeastern Wollega (Figure 2.5). This process has encouraged destruction of natural habitats, disruption of ecosystem's functions, and threatened tree species (e.g., *Juniperous procera* (Tid), *Podocarptus falcatus* (Zigba), *Olea europaea* (Woyera) and *Rosa abyssinica* (Kega). The rate of deforestation in the study area can be compared with results of studies conducted elsewhere in Ethiopia. For example, in the Kalu area, northeastern Ethiopia, forest cover declined from approximately 8% to 5% between 1958 and 1986 (Hedlund & Kebrom, 2000). In the Dembecha district, northwestern Ethiopia, Gete & Hurni (2001) reported losses in natural forest cover from approximately 27% to less than 1% between 1957 and 1995. Despite this, there are a few examples where forest cover increased, which are documented in studies by Woldeamlak (2002) and more recently by Asmamaw, Mohammed & Lulseged (2011).

Excessive deforestation has presumed impacts on hydrological system, particularly water shortages or changes in rainfall (Figure 2.6). Deforestation decreases rainfall and may cause erosion and flooding. Expansion of agriculture towards steeper areas reduces the downstream supply of water from those areas (Figure 2.7). Figure 2.7 (locally known as *Chunkulle* River) was taken during the month of September, one of the wettest month in the study area. The river course should have been filled with water, but currently it was converted into marshland. Key informant interview report that the river was impossible to cross during September. However,

due to deforestation and irrigation around the marshes of the river, the volume of the river was being shrunk.



Figure 2.5: Evidences of deforestation in Northeastern Wollega, Ethiopia

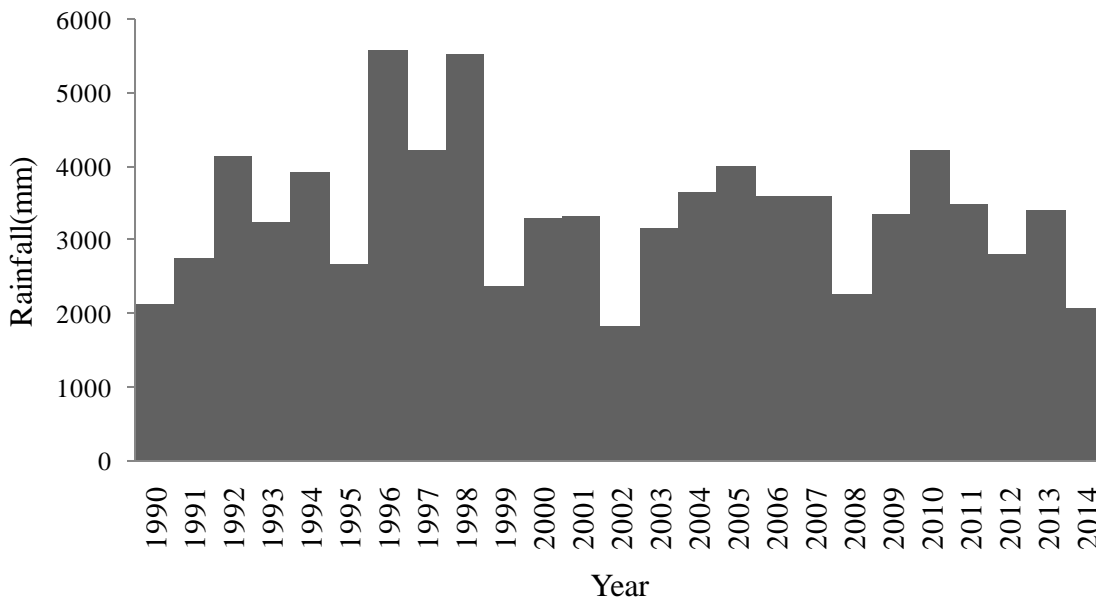


Figure 2.6: Trends of rainfall (mm) in Northeastern Wollega, Ethiopia



Figure 2.7: Water shortage in Northeastern Wollega, Ethiopia

Deforestation also reduces land quality and agricultural productivity (Lambin et al., 2003). As it was indicated in Figure 2.8, the productivity of major cereal crops, except maize, remained stagnant in the last five years. Respondents explained that they collected similar harvests every year despite the fact that their chemical fertilizer application per capita is increasing during the same period.

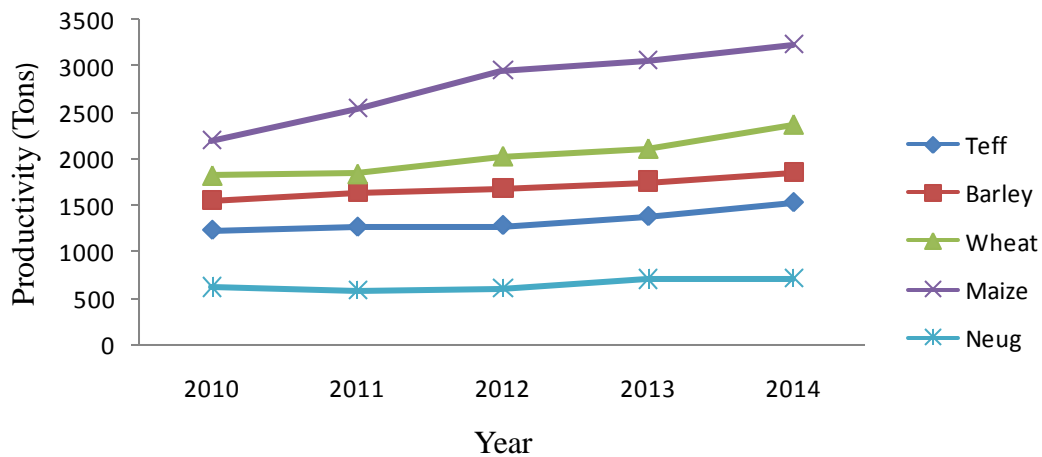


Figure 2.8: Productivity of major crops in Northeastern Wollega, Ethiopia

Conclusions

This study identified changes in land-use/land-cover between 1972 and 2015. The area under cropland was increased by approximately 75% between 1972 and 2005. However, areal extent of cropland declined since 2005. Shrubland generally increased by 19% during the study period (1972-2015), while it was highest (22%) during the third period (2005-2015). This implies that some portions of degraded lands are being reversed because of soil and water conservation practices carried out by the current government. On the contrary, forestland has declined by about 36% in the study period. The drivers were identified as population growth, rising number of livestock, poor farming practices and tenure insecurity. The population increased nearly three-fold from 19,942 in 1972 to 58,339 in 2014, which therefore reduced the land per capita available for arable production.

In general, land-use/land-cover changes in northeastern Wollega resulted in destruction of natural habitats, disruptions of ecosystem's functions, land fragmentations, threatening tree species, water shortage, changes in rainfall, reduced land quality and agricultural productivity. Given these facts, land-use/land-cover changes imply for the prevalence of land degradation in the study area. The trend observed imply that the demand towards cropland will likely continue, including expansion into more marginal, fragile land. Based on the data reported in this study and the scientific literature available for the study area, improving agricultural practices and land tenure systems, and controlling population growth are encouraged.

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Chapter 3

Random and systematic land-cover transitions in Northeastern Wollega, Ethiopia

Alemayehu Adugna^{1, 2*}, Assefa Abegaz¹, Asmamaw Legass¹, Diogness L. Antille

Random and systematic land-cover transitions in Northeastern Wollega, Ethiopia

Abstract

Land-cover transition is derived by various land management decisions made by different land users. The objective of the present study was to examine whether land-cover transitions were random or systematic in Northeastern Wollega (Ethiopia) using detail statistical analysis of land-cover transition matrices. Land-cover transition matrix from two Landsat images (2005 and 2015) was used to detect proportions, swap, loss, gain, persistence, vulnerability and process of land-cover changes. Results revealed that shrubland experienced the highest gain (22%), gain-to-loss ratio (63), gain-to-persistent ratio (47%) and positive net change-to-persistence ratio. Cropland experienced the highest loss (19%), but it is the highest persistent land-cover. Grassland is the most stable land-cover in the area. The transition process in the study area is dominated by systematic processes of change and with very few random processes of change. This can be interpreted as land-cover transitions, particularly agriculture abandonment and vegetation regrowth, are due to regular or common processes of change. From this process, it is possible to predict changes that are likely to occur, proposed management options that might be successful for a given biophysical, socio-economic and political situation, and what the potential impacts on environment and rural livelihood. This study further suggests labor forces are being withdrawn from agriculture and join non-agricultural economic sectors.

Key words: agricultural abandonment; cropland; Ethiopia; re-growth; vulnerability

Introduction

Land-cover transition is a reflection of the decisions made by different land users and can take place at different spatial scales (Carmona & Nahuelhual, 2012; Belay, Van Rompaey, Poesen, Van Bruyssel, Deckers & Amare, 2015). At large scale, land-cover transition is a process of system change in which the structure of the land-use system is transformed (Ouedraogo, Tigabu, Savadogo, Compaore, Oden & Ouadba, 2010; FAO, 2015). Specifically, the concept of land-cover transition refers to any change in land-use system from one cover to another (e.g., from a system dominated by forestland to a system with cropland in response to agricultural expansion or extensification) (Zucca, Wu, Dessena & Mulas, 2015). In most cases, the common forms of transitions could be the expansion of subsistence crop production into

ecologically marginal areas, deforestation and afforestation (Teferi, Bewket, Uhlenbrook & Wenninger, 2013).

On the other hand, land-cover transitions can be classified into random and systematic changes (Pontius, Shusas & McEachern, 2004; Brianoh, 2006). If the transition involves abrupt or unique process of change, the land-cover transition is identified as random (Carmona & Nahuelhual, 2012). Rapid land-cover transition is often followed by quick recovery of ecosystems (König, Zhen, Helming, Uthes, Yang, Cao & Wiggering, 2015). The magnitude of land-cover transition depends on the resilience and feedback mechanisms of land-cover (Singh, Nayak, Sharma, Singh, Mishra & Singh, 2015; Zucca et al., 2015). Random land-cover change is caused by unexpected land-use factors, such as spontaneous migration, internal conflicts, insecure land tenure or changes in macroeconomic conditions and other factors of production (Lambin, Geist, & Lepers, 2003; Carmona & Nahuelhua, 2012). In turn, systematic transitions are those because of permanent, stable or familiar processes of changes. The most likely causes are natural population growth, expansion of agricultural commercialization, frontier development, absence of public education on the environmental management or dynamics in institutions that control the right to use to resources (Lambin et al., 2003; Siren, 2007).

However, the conventional meanings of random and systematic land-cover transitions stated above are different from the statistical meanings proposed by Pontius et al. (2004). Conventional meanings are attributed to causal factors of change (Belay et al., 2015). The statistical meanings, on the other hand, are exclusively attributed to the detailed examination of the land-cover matrix (Oudraogo, Barron, Tumbo & Kahimba, 2015). In the statistical meanings, land-cover class gains randomly from others if the gains are in proportions to the presence of those losing classes. In the same way, the land-cover class losses randomly to others if the losses

are in proportions to the extent of other gaining classes. Any big positive or negative difference from those proportions is referred to as a systematic land-cover change (Versace, Ierodiaconou, Stagnitti & Hamilton, 2008).

Measuring statistically random and systematic land-cover transitions encourage land-users, researchers and planners to emphasize on the most important sign of changes (Versace et al., 2008). This quantitative approach is important to minimize the adverse effects of land-cover change on the environment and rural livelihood. Satellite imageries taken at different time series are emerged as the most important data source for quantitative measurement of land-cover transitions at the landscape scales (Petit, Scudder & Lambin, 2001; Shiferaw, Okello & Reddy, 2009). From the satellite images, two-dimensional transition matrix tables, which summarize land-cover changes between dates, are constructed. Cross-tabulation matrix compares land-cover at one time (t_1) with that of another (t_2). Detailed analysis of the various components of the transition matrix, such as amount, location, types and the process involved in land-cover transitions, carried out from the images. Many studies highlighted that detecting land-cover transitions are useful for developing adaptive land management policies (Braumoh, 2006; Versace et al., 2008; Ouedraogo, Runge, Eisenberg, Barron & Sawadogo/Kaboré, 2014; Carmona & Nahuelhua, 2012; Teferi et al., 2013; Angonese & Grau, 2014; Teshome, de Graaff, Ritsema & Kassie, 2014; Ouedraogo et al., 2015).

The objective of the present study was to detect and examine dominant signs of land-cover transition in Northeastern Wollega (Ethiopia) using detail statistical analysis of land-cover transition matrices proposed by Pontius et al. (2004). The main reason for choosing Northeastern Wollega for the study was that the region is considered as one of the most affected by deforestation (Adugna, Abegaz, Bahir & Antille, 2016). This area is also characterized by rapid

population growth due to immigration of farmers from drought affected and land shortage zones of the country. Despite the implementation of soil and water conservation during the last 30 years, the environment continues to degrade (Adugna & Abegaz, 2016). These are evidenced by the destruction of vegetation cover, depletion of soil fertility and intense erosion, with land-cover change being one of the causes. Unlike previous studies conducted elsewhere (e.g., Gette & Hurni, 2001; Desse & Kleman, 2006; Asmamaw, Mohammed & Lulseged, 2011), which recognize patterns and dynamics of land-cover as straightforward and irreplaceable change, our analysis emphasizes the most recent change and discusses the process of land-cover transitions. In this study, we propose that land-cover changes are replaceable and the relationship among drivers is complex (Crk, Uriarte, Corsi & Flynn, 2009; Carmonaa & Nahuelhual, 2012). Furthermore, this research represents the most recent and detailed spatio-temporal analysis of land-cover transition conducted in the northeastern Wollega, Ethiopia. Therefore, it is necessary to understand and quantify the process of land-cover transition to ensure a sustainable management of natural resources.

Materials and methods

Data sources

Landsat images of 2005 and 2015 of the area were used to detect land- cover transitions. The two images have geometrically rectified into the Universal Transverse Mercator-World Geodetic System (UTM-WGS 84 zone 37) ahead of change detection. This has been done using topographic maps and digital elevation model images. A tasseled cap orthogonal transformation of the original bands was carried out to improve the visual classification of land-cover types. Land-cover classification was performed using the supervised maximum likelihood algorithm classifier to allocate pixels to land-cover classes (Oudraogo et al., 2015). These have required

thorough ground truthing procedure in the study area in 2015, which include collection of ground control points, training samples, ground check and validation. The number of samples (n) for each land-cover classes was selected by using the following equation from the multinomial distribution:

$$n = \frac{B\Pi_i(1-\Pi_i)}{b_i^2} \quad (3.1)$$

where: $B=6.63$ which is the upper $\left(\frac{\alpha}{k}\right) \times 100^{th}$ percentile of the χ^2 distribution with one degree of freedom, while α is 0.01 level of significance and $\Pi_i(i=1\dots k)$ is the proportion of the population in the i^{th} category, and b is the absolute precision of the sample, k is number of land-cover categories.

This equation is calculated for each of ' k ' categories and ' n ' for all categories is then selected proportion to the size of the category. The analysis is used at 95% confidence level, which is considered appropriate based on related studies, and the absolute precision was set at 0.05. For the study site, ' n ' from the smallest class was chosen as the desired sample size to match Congalton & Green's (1999) rule of thumb of a minimum of 50 samples. Stratified random sampling methods were used to collect an optimum number of sample reference polygons for the classification accuracy assessment. The population (sampling frame), land-cover classes, embraces distinct categories (separate strata): forestland, shrubland, grassland, cropland and settlement. Each stratum is then sampled as an independent sub-population, from which individual elements can be randomly selected (Table 3.1). Producer's accuracy (measure of omission error) was computed by dividing the total number of correct pixels in a category by the total number of pixels of that category as derived from the reference data (the column total). This procedure illustrates how well a certain area can be classified or indicates the probability of

a reference pixel being correctly classified. The user's accuracy, that is, a measure of commission error is computed by dividing the total number of correct pixels in a category by the total number of pixels that were classified in that category (the row total). This procedure is a measure of reliability, which indicates the probability that a pixel classified on the map/image actually represents that category on the ground. The overall accuracy was 76.7% for 2005 and 80% for the 2015 land cover map.

Table 3.1: Land-cover, sample size, producer's accuracy and user's accuracy assessment in Northeastern Wollega, Ethiopia

No.	LULCC	Sample size (n)	Producer's accuracy (%)	User's accuracy (%)
1	Forestland	483	79.4	71.1
2	Shrubland	50*	71.4	68.2
3	Grassland	239	70.2	73.9
4	Cropland	620	76.6	84.1
5	Settlement	70	86.0	84.2

Note: *For shrubland, 50 sample sizes were chosen as the desired sample size close to Congalton & Green's (1999) rule-of-thumb of a minimum of 50 samples per class since the value was small to consider for the study using equation 1.

In total, the land-covers in the study area were classified into five categories (Lambin et al., 2003). These include forestland (high and dense trees with 70-100% closed canopy), shrubland (bush canopy mixed with some trees, area closure, plantations and grass), grassland (mainly grasses without, long-fallowed land or with less than 10 trees per hectare), cropland (agricultural land with crops and harvested agricultural land), and settlement (built up areas).

Data analysis

Land-cover transition matrix

Land-cover transitions were analyzed using a transition matrix obtained from cross-tabulation of the two-raster maps presented above. We used the methodology demonstrated by Pontius et al. (2004), which can identify major signals of systematic land-cover changes. The general structure of the transition matrix was demonstrated in such a way that the columns and rows present the proportions of the five land-cover classes in 2015 and 2005, respectively (Table 3.2). The notation C_{ij} (where $i \neq j$) designates the proportion of the landscape that experienced a transition from class i to class j between 2005 and 2015. The main diagonal elements (i.e., C_{ij}) designate the proportion of persistent land-cover classes (that showed no change). Diagonal elements are used to calculate the gains and the losses of land-cover classes (Pontius et al., 2004). The off-diagonal elements showed the amount of the land-cover transformed from class i to class j between 2005 and 2015. The proportions of the land-cover, C_{i+} and C_{+j} , that were enclosed by class i in 2005 and class j in 2015 were calculated using equation (3.2) and (3.3), respectively (Pontius et al., 2004; Ouedraogo et al., 2011).

$$C_{i+} = \sum_{j=1}^n C_{ij} \quad (3.2)$$

$$C_{+j} = \sum_{i=1}^n C_{ij} \quad (3.3)$$

Where, n is the total number of classes.

The loss column indicates that the amount of the land-cover that experienced a gross loss of class i between 2005 and 2015, whereas the gain rows shows the amount of the land-cover that experienced a gross gain of class j between the two years (Table 3.2).

The idea of ‘swap’ entails concurrent gain and loss of a given land-cover classes in the area. Equation 3.4 describes the proportions of swap that requires the pairing of each pixel that loses with the pixel that gain (Braimoh, 2006).

$$S_j = 2 \times \min(C_{j+} - C_{jj}, C_{+j} - C_{jj}) \quad (3.4)$$

Where S_j is swap, for each category j , as twice the minimum of the gain and loss.

Vulnerability of land-cover to transition

The vulnerability of each land-cover class to transition is calculated using the gain-to-persistence ratio ($G_p = g p^{-1}$), the loss-to-persistence ratio ($L_p = l p^{-1}$) and the net change-to-persistence ($N_p = G_p - L_p$) (Ouedraogo et al., 2010). g , p and l stands for gain, persistence and loss, respectively. Value of G_p and L_p greater than one imply that a given land-cover class has a greater likelihood to change to other land-cover classes than persist (Braimoh, 2006). If the value of N_p is negative, the land-cover class has a greater likelihood to loss area to other land-cover classes than to gain from them.

Table 3. 2: A 5×5 land-cover matrix

2005	2015					Total 2005	Loss
	Forestland	Shrubland	Grassland	Cropland	Settlement		
Forestland	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{1+}	$C_{1+}-C_{11}$
Shrubland	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{2+}	$C_{2+}-C_{22}$
Grassland	C_{31}	C_{32}	C_{33}	C_{34}	C_{35}	C_{3+}	$C_{3+}-C_{33}$
Cropland	C_{41}	C_{42}	C_{43}	C_{44}	C_{45}	C_{4+}	$C_{4+}-C_{44}$
Settlement	C_{51}	C_{52}	C_{53}	C_{54}	C_{55}	C_{5+}	$C_{5+}-C_{55}$
Total 2015	C_{+1}	C_{+2}	C_{+3}	C_{+4}	C_{+5}	1	
Gain	$C_{+1}-C_{11}$	$C_{+2}-C_{22}$	$C_{+3}-C_{33}$	$C_{+4}-C_{44}$	$C_{+5}-C_{55}$		

Note: C is any conversion from one land-cover to another

Detection of systematic and random transitions

The 2005 and 2015 land-cover data were used to analyze the recent land-cover transition processes in the northeastern Wollega for the study period. The procedures applied to detect the random and systematic process of change in northeastern Wollega are the same procedure applied by Pontius et al. (2004), Braimoh (2006), Ouedraogo et al. (2014) and Ouedraogo et al. (2015). The detection of systematic and random inter-category transitions involves four inter-related procedures. The first procedure calculates the expected gain (G_{ij}) for each class under a random process of gain using equation 3.5 (Pontius et al., 2004).

$$G_{ij} = (C_{+j} - C_{jj}) \left(\frac{C_{i+}}{\sum_{i=1}^j C_{i+}} \right) \quad (3.5)$$

Equation (3.5) distributes the gain across the off-diagonal entries of 2015 according to the relative proportions of the other classes in 2005. The assumption of this equation is that the gain of each class and the proportion of each class in 2015 are unchanged. These expected gains represent the random process of gain.

The second procedure calculates the difference between the observed (measured) and expected proportions of gain under a random process of gain. Big positive or negative differences from zero signify systematic inter-category transition, rather than random transitions, happen between two land-cover classes. The bigger a positive calculated variance, the bigger the area affected by systematic gain of class j from class i and the larger a negative calculated variances, the weaker the tendency of class j to gain systematically from class i (Braimoh, 2006; Ouedraogo et al., 2010). The third procedure calculates the expected loss, L_{ji} (loss of class i to class j) under a random process of loss using equation 3.6 (Braimoh, 2006):

$$L_{ij} = (C_{i+} - C_{ii}) \left(\frac{C_{+j}}{\sum_{i=1}^j C_{j+}} \right) \quad (3.6)$$

The assumption of Equation (3.6) is that the loss of each land-cover class is fixed and the loss in each row across the other classes is distributed relative to their proportions in 2015. The forth procedure calculates the difference between the observed and expected proportions of gain under a random process of loss. Likewise, big positive or negative differences from zero signify systematic inter-category transition, rather than random transitions have happened between two land-cover classes. The bigger a positive calculated variance, the higher the area affected by systematic loss of class *i* to class *j* and the larger a negative calculated variances, the weaker the tendency of class *i* to systematically loss to class *j* (Braimoh, 2006; Ouedraogo et al., 2010). Generally, it can be concluded that the transition from class *i* to class *j* is a systematic process if class *i* loses systematically to class *j*, and class *j* gains systematically from class *i* (Pontius et al., 2004).

Results

Summary of land-cover transitions

Table 3.3 shows the proportions and changes of land-cover. In 2005 and 2015, the area of forestland accounted for 24% and 11% of the area, respectively. The area of cropland dropped from 63% in 2005 to 55% in 2015, while grassland area remained almost stable during the study period (Table 3.3). Area of shrubland increased from just 1% to 23% between 2005 and 2015. Between the two years, the shrubland gained more, while forestland and cropland experienced more loss. The loss in area of cropland is highest constituting 19% of the landscape. The gain-to-loss ratio was highest (63) for shrubland followed by settlement (2). The gain-to-loss ratio is lowest for forestland (0.2), followed by cropland (0.6). Change attributable to location (swap)

was highest for cropland (24% of the change in cropland), followed by grassland (15% of the change in grassland) and forestland (7% of the change in forestland) (Table 3.3). Change related to quantity (net change) was highest for shrubland (22%), followed by forestland (13%) (Table 3.3).

Table 3.3: Proportions of land-cover change (%) in the Northeastern Wollega, Ethiopia

	Total 2005	Total 2015	Persistence	Gain	Loss	Total Change	Swap	Absolute value of net change
Forestland	23.92	11.16	7.76	3.40	16.16	19.56	6.81	12.75
Shrubland	0.82	22.51	0.47	22.03	0.35	22.38	0.69	21.69
Grassland	9.94	8.32	1.07	7.25	8.86	16.11	14.50	1.61
Cropland	62.64	55.20	43.44	11.76	19.20	30.96	23.51	7.44
Settlement	2.68	2.81	0.29	2.52	2.40	4.92	4.79	0.13
Total 2015	100.00	100.00	53.03	46.97	46.97	93.93	50.31	43.63

Persistence and vulnerability of land-cover

The proportions of different land-cover classes that did not change (persistent) from 2005 to 2002 are shown the diagonal of table 3.4. The proportion of persistence was highest for cropland (about 43% of landscape that was cropland in 2005). Settlement areas have experienced the lowest persistence of the landscape (0.26%). Among the natural vegetation, grassland experienced the highest persistence (8%), whereas shrubland experienced the lowest in 0.50% of the landscape (Table 3.4). The vulnerability of land-cover classes to transition is shown in table 5. The gain-to-persistence ration (G_p) and was higher than one for all land-cover classes except for forestland and cropland. G_p was highest for shrubland (47) and lowest for cropland (0.27). The loss-to-persistence ratio (L_p) for all land-covers except cropland and shrubland is higher than 1. L_p was highest for grassland (8) and lowest for cropland (0.44).

Table 3.4: Land-cover change matrix (%) between 2005 and 2015 in the Northeastern Wollega, Ethiopia

	2015						
2005	Forestland	Shrubland	Grassland	Cropland	Settlement	Total 2005	Loss
Forestland	7.76	9.37	1.79	4.86	0.14	23.92	16.16
Shrubland	0.07	0.47	0.06	0.21	0.00	0.82	0.35
Grassland	0.72	2.84	1.07	5.08	0.22	9.94	8.86
Cropland	2.43	9.39	5.22	43.44	2.16	62.64	19.20
Settlement	0.18	0.43	0.18	1.61	0.29	2.68	2.40
Total 2015	11.16	22.51	8.32	55.20	2.81	100.00	46.97
Gain	3.40	22.03	7.25	11.76	2.52	46.97	

The net change-to-persistence (N_p) is positive for shrubland (46) and negative for the other land-cover classes (Table 3.5). The N_p value was the highest for shrubland (46), followed by settlement (-7). On the other hand, the value of N_p was the lowest (-0.17) for cropland (Table 3.5).

Table 3.5: Gain-to-persistence (G_p), loss-to-persistence (L_p), and net change-to-persistence (N_p) ratios of the land-cover classes in the Northeastern Wollega, Ethiopia.

	Gain (g)	Loss (l)	Persistence (p)	G_p	L_p	N_p
Forestland	3.40	16.16	7.76	0.44	2.08	-1.64
Shrubland	22.03	0.35	0.47	46.88	0.74	46.14
Grassland	7.25	8.86	1.07	6.77	8.28	-1.51
Cropland	11.76	19.20	43.44	0.27	0.44	-0.17
Settlement	2.52	2.40	0.29	1.05	8.26	-7.21

Systematic and random process of change within northeastern Wollega

The expected gains for each land-cover class under random process of gain are demonstrated in table 3.6(a), and the difference between the observed and expected gains in table 3.6(b). The differences between observed and expected gains for cropland-forestland and forestland-cropland transitions are 0.30% and 2%, respectively. This implies that forestland randomly gained 2% of the landscape from cropland, whereas cropland systematically gained 5% of the landscape from forestland. The differences between observed and expected gains for forestland-shrubland and cropland-shrubland transitions are 4% and -4%, respectively (Table 3.6b). This shows that there is systematic exchange of forestland and cropland with shrubland. Shrubland gained systematically gained 9% of the landscape from forestland and cropland. The difference between observed and expected gain for cropland-grassland and grassland-cropland transitions are 0.70% and 40%, respectively. This shows that there is systematic exchange between cropland and grassland. Grassland systematically gained 5% of landscape from cropland, whereas cropland systematically gained 5% of the landscape from grassland. The differences between observed and expected gains for forestland-settlement and cropland-settlement transitions are -0.50% and 0.60%, respectively. This implies that settlement systematically gained 0.14% and 2% of the landscape from forestland and cropland, respectively.

The expected losses under a random process of loss are given in table 3.7(a) and the difference between the observed and expected losses in table 3.7(b). The differences between observed and expected loss for forestland to shrubland transition was 9%, indicating that forestland systematically lost to shrubland. The differences between the observed and expected losses for forestland to cropland and for cropland to forestland transitions were 2% and -6%, respectively (Table 3.7b).

Table 3.6: Intercategory gains in the Northeastern Wollega, Ethiopia: (a) expected gains and (b) difference between observed and expected

	2005					2015	
	Forestland	Shrubland	Grassland	Cropland	Settlement	Total 2005	Loss
(a) Expected gains under a random process of gain (%)							
Forestland	7.76	5.27	1.73	2.81	0.60	18.18	10.42
Shrubland	0.03	0.47	0.06	0.10	0.02	0.68	0.20
Grassland	0.34	2.19	1.07	1.17	0.25	5.02	3.95
Cropland	2.13	13.80	4.54	43.44	1.58	65.50	22.06
Settlement	0.09	0.59	0.19	0.32	0.29	1.48	1.19
Total 2015	10.35	22.33	7.60	47.84	2.74	90.85	37.82
Gain	2.59	21.85	6.53	4.39	2.45	37.82	
(b) Difference between the observed land-cover transitions and the expected gain (%)							
Forestland	0.00	4.10	0.05	2.05	-0.46	5.74	5.74
Shrubland	0.05	0.00	0.00	0.11	-0.02	0.14	0.14
Grassland	0.38	0.65	0.00	3.91	-0.03	4.92	4.92
Cropland	0.30	-4.41	0.68	0.00	0.58	-2.85	-2.85
Settlement	0.09	-0.16	-0.02	1.30	0.00	1.20	1.20
Total 2015	0.81	0.18	0.72	7.37	0.07	9.15	9.15
Gain	0.81	0.18	0.72	7.37	0.07		

The large and negative value of cropland to forestland transitions implies that cropland systematically avoided losing to forestland. The difference between observed and expected loss for cropland to shrubland, cropland to grassland and cropland to settlement transitions were 9, 4 and 1%, respectively, indicating that cropland has tended to lose systematically to other land-cover classes.

Table 3.7: Intercategory losses in Northeastern Wollega, Ethiopia: (a) expected loss; (b) difference between observed and expected loss.

	2005					2015	
	Forestland	Shrubland	Grassland	Cropland	Settlement	Total 2005	Loss
(a) Expected losses under a random process of loss (%)							
Forestland	7.76	0.04	0.99	2.14	0.27	11.20	3.44
Shrubland	3.64	0.47	1.99	4.32	0.54	10.96	10.49
Grassland	1.34	0.03	1.07	1.60	0.20	4.25	3.17
Cropland	8.92	0.19	0.74	43.44	1.32	54.62	11.17
Settlement	0.45	0.01	0.25	0.54	0.29	1.54	1.25
Total 2015	22.11	0.74	5.04	52.05	2.61	82.56	29.53
Gain	14.35	0.27	3.97	8.60	2.33	29.53	
(b) Difference between the observed landscape transitions and the expected loss (%)							
Forestland	0.00	9.33	0.80	2.05	-0.46	11.71	11.71
Shrubland	-3.56	0.00	-1.93	0.11	-0.02	-5.40	-5.40
Grassland	-0.63	2.81	0.00	3.91	-0.03	6.07	6.07
Cropland	-6.49	9.20	4.48	0.00	0.58	7.77	7.77
Settlement	-0.27	0.42	-0.07	1.30	0.00	1.37	1.37
Total 2015	-10.95	21.76	3.28	7.37	0.07	21.52	21.52
Gain	-10.95	21.76	3.28	7.37	-0.07	21.39	

Discussion

The results show that shrubland represented the least dominant land-cover in 2005. However, in 2015, it was the second most dominant represented land-cover next to cropland. The highest gain-to-loss ratio of shrubland indicates that it experienced 63 times more gain than loss. The assessment of vulnerability of land-cover to transition also showed G_p values for shrubland

is highest (47). This indicates that shrubland has a tendency to gain rather than persist. The gain in shrubland was due to degradation of forestland to shrubland (9%), afforestation on land previously under non-forest land use, shrubland improvement to protected areas and expansion of natural forest in areas previously under crop cultivation to enhance regrowth and rehabilitation of degraded land (Lambin et al., 2003; Bewket, 2007). The apparent increase of shrubland could also be associated with Environmental Policy of Ethiopia (EPE, 1997). EPE encourages tree planting such as the development of forestry on farms, around homesteads, and/or eroding hillsides. They prevented illegal hunting, bushfire and free mobility of livestock to improve secondary forest cover in the protected areas. The policy also directed towards the management of forests, trees and woodland resources for sustainable and participatory natural resource management (Teshome et al., 2014).

Loss in forestland is most likely due to deforestation for agricultural expansion and logging for firewood and charcoal production (FAO, 2015). The assessment of land-cover transition process reveals that forestland systematically transformed to cropland. This implies that farmers preferentially cleared forestland to make a space for new farmland (Konig et al., 2014). Conventionally, people have increased agricultural output by getting more forestland into production (Ndah, Schuler, Uthes, Zander, Triomphe, Mkomwa & Corbels, 2015). Large-scale forest conversion and expansion of livestock-based farming means the amount of suitable land remaining for crops is very limited in northeastern Wollega. Thus, in 2005, cropland experienced loss and decrease during the last decade although it is still the most dominant land-cover. The loss was associated with abandonment of cropland due to soil degradation. Similar findings have been reported in other studies conducted elsewhere (e.g., Schneider & Geoghegan, 2006; Carmona & Nahuelhual, 2012; Angonese & Grau, 2014).

The lowest Gp value (0.27) for cropland indicates that this land-cover type has tended to lose to other cover types. This means that there were large swaps resulting from coincident gains and losses of similar scale (Table 3.3). This implied a relocation of 24% of cropland, which, in turn, reflects a process of agricultural adjustment (Carmona & Nahuelhual, 2012). Agricultural adjustment means a relocation of agricultural lands into more fertile areas (Konig et al., 2014). This system plays a critical role in promoting re-growth. While this process did occur in the northeastern Wollega, other factor related to rural environment could intervene. For example, spontaneous abandonment of agricultural production by farmers on degraded land is considered as one of the main drivers behind deforestation reversal and consequent forest re-growth (Singh et al., 2015). Land abandonment can be attributed to different causal factors, for instance, agricultural system changes toward extensification or intensification derived by economic condition and social environment (Díaz, Nahuelhual, Echeverría, & Marín, 2012; Vermeulen et al., 2013). The options for opening of new land from forest, wetlands, hillsides or pastures for cultivation are becoming limited or impractical and it will soon not be sustainable as a strategy for increasing production. However, intensification has not been common in the study area. First, the area has been land-rich and supportive of extensification (land-demanding strategy). Secondly, intensification is risky and costly, driven by inadequate market development, inadequate resource allocation, technological limitations, withdrawal of needed labor, tenure insecurity, lack of awareness of issues and alternatives, and environmental degradation. Therefore, farmers often forced to make intensification a poor alternative. Farmers require input to intensify agricultural production on their land, and adopt achievable level of intensification (labor-demanding or capital-deficient intensification) that partly relies on government support in the form of loans and subsidies. The following requirements are suggested to provide the correct

environment for sustainable intensification of agriculture: agriculture is commercialized, input and output markets are accessible, investment returns are high, population pressure is high, labor is available and farmers have cash to buy inputs (Wood, Tappan & Hadj, 2004).

Due to economic progress, labor forces withdrawn from agriculture and join non-agricultural economic sectors that involve migration from rural to urban areas (Pretty, Toulmin & Williams, 2011). Agricultural abandonment has both positive and negative consequences on the environment and rural livelihood (Izquierdo & Grau, 2009; Barbier, Burgess & Grainger, 2010; Teixeira, Teixeira & Marque, 2014). The negative consequences of land abandonment include the disappearance of traditional farming practices, poverty, food shortage and invasion of exotic species (Zucca et al., 2015). Contrarily, agricultural abandonment allows the revival of ecosystem services and therefore is beneficial for human being and environment (Konig et al., 2014). In this study, we view agricultural abandonment as a process that involves steady conversion of the land from agricultural use toward natural vegetation.

Our results show that the transition of landscape from cropland to shrubland, grassland and settlement was due to systematic process of change. Hence, local farmers seem to preferentially fallowed and abandoned cropland to make space for pasture production and expansion of agroforestry. This suggests that there is a shift from farming only to livelihood diversification activities, such as cattle fattening, trade, handicraft and service provisions.

Conclusions

The land-cover changes as demonstrated by this study can be interpreted as a sign of agricultural land retirement and restored ecological landscape. Among the studied land-cover classes, shrubland experienced the highest gain, whereas cropland experienced the highest loss.

As a result, cropland abandonment and secondary forest re-growth can be identified as major land-cover transitions in the area. Empirical evidences demonstrated by this study suggest that land-cover transition is an indication of responses to degraded circumstances. This can help farmers to conserve natural resources by converting some of agricultural and grazing fields into secondary forest re-growth. This approach calls for agricultural intensification and diversification related policies to circumvent rising pressure on forests. Then, higher agricultural yield will be emphasized to reduce to search for extra agricultural area. This paper, however, shows that the speed and stage of land-cover transition are determined by biophysical factors and human involvement that have enhanced the regeneration of vegetation cover.

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Chapter 4

Effects of Land-use/Land-cover Changes on the Mean Differences of Soil Properties in the Northeastern Wollega, Ethiopia

Alemayehu Adugna and Assefa Abegaz

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Effects of Land-use/Land-cover Changes on the Mean Differences of Soil Properties in the Northeastern Wollega, Ethiopia

Abstract

Land use change can have negative or positive effects on soil quality. Our objective was to assess the effects of different land uses types on the mean differences of selected soil physical and chemical properties. Soil samples were collected from three adjacent soil plots under different land uses, namely forestland, grazing land and cultivated land at 0–15 cm depth. Differences of soil properties on cultivated and grazing land was computed and compared to forestland as control, and ANOVA were used to test the significance of the changes. Sand and silt proportions, soil organic content, total nitrogen content, acidity, cation exchange capacity, and exchangeable Ca^{2+} content were higher in forestlands. Exchangeable Mg^{2+} was highest in grazing land while clay, available phosphorous and exchangeable K^+ was highest in cultivated land. The mean difference in sand, clay, soil organic matter, cation exchange capacity, exchangeable Ca^{2+} and Mg^{2+} were higher in cultivated land than the change in grazing land compared to forestland. In terms of relation between soil properties; soil organic matter, total nitrogen, cation exchange capacity and exchangeable Ca^{2+} were strongly positively correlated with most of soil properties while available phosphorous and silt have no significant relationship with any of other considered soil properties. Clay has negative correlation with all of soil properties. Generally, the current cultivated land has the least concentration of soil physical and chemical properties except clay and available phosphorous which suggest increasing degradation rate in soils of cultivated land. So as to increase soil organic matter and other nutrients in the soil of cultivated land, integrated implementation of land management through compost, cover crops, manures, minimum tillage and crop rotation; and liming to decrease soil acidity are suggested.

Keywords: cation exchange capacity, land degradation, organic matter, soil acidity, soil texture

Introduction

Land use changes have remarkable effects on the dynamics of soil properties (Biro, Pradhan, Muchroithner & Makeschin, 2013). Land use changes from forest cover to cultivated land may reduce the input or organic residues that lead to a decline in soil fertility (Muñoz-Rojas, Jordán, Zavala, De La Rosa, Abd-Elmabod & Anaya-Romero, 2015), and increase rates of erosion (Biro et al., 2013), loss of soil organic matter and nutrient (Saha & Kukal, 2015), and

accelerate rate of soil degradation (Barua & Haque, 2013). Vegetation cover is, therefore, a key indicator of soil degradation as plants play a role in the control of soil erosion (Kröpfl, Cecchi, Villasuso & Distel, 2013; Keesstra, Bruijnzeel & van Huissteden, 2009; Cerdà, 1998). Biro et al. (2013) observed expansion of cultivated areas can substantially affect soil nutrient content by reducing composition of plant species, net primary productivity, above and belowground allocation in plants, and nutrient cycling. Soil organic matter is lesser in extremely degraded areas where overgrazing manifested. Saha & Kukal (2015) found higher bulk density and lower macro-porosity and water retention in cultivated soils than soils of grassland and forests. These indicated a degradation of soil properties due to the conversion of natural ecosystem to agricultural system.

In Ethiopia, rapid population growth and environmental factors lead to the conversion of natural forest and grassland into cultivated farmland (Tesfahunegn, 2013). Such land use changes have contributed to soil degradation and soil loss by deteriorating the soil physical and chemical properties (Karlton, Lemenih & Tolera, 2013). Soil compaction, loss of soil structure, SOM degradation, undulating terrain, highly erosive rainfall and inappropriate farming practices make soil highly vulnerable to soil erosion. Soil erosion is highest in cropland (42 mt per hectare average annual rate) compared with 5 mt per hectare from grassland. Soil degradation causes loss of fertile topsoil and reduces the productive capacity of the land. The country lost an estimated USD 1 billion per year from both on-site and off-site changes (Bewket & Teferi, 2009). This has been confirmed by empirical studies carried out in different parts of Ethiopia (e.g., Angassa, 2014; de Mulenaere et al., 2014; Tesfaye, Negatu, Brouwer, & Van Der Zaag, 2014; Tesfahunegn, 2013; Asmamaw & Mohamed, 2013; Fantaw & Abdu, 2011; Eyayu, Heluf, Tekalign, & Mohammed, 2009). Soil degradation in the area makes necessary to apply

restoration strategies (Mekonnen, Keesstra, Stroosnijder, Baartman & Maroulis, 2015; Bizoza, 2014; Zhang, Wang, Y., Wang, X., Wang, Q., & Han, 2013). Soil protection is fundamental to keep sustainable services of the soils and avoid land degradation (Berendse, van Ruijven, Jongejans & Keesstra, 2015; Keesstra, Geissen, van Schaik, Mosse & Piirainen, 2012).

In a study conducted in the rift valley area of Ethiopia, Fantaw & Abdu (2011) recounted an increase in bulk density and decrease in soil organic matter (SOM), total nitrogen (TN), exchangeable cations and cation exchange capacity (CEC) contents following the conversion of native woodlands into farmland and grazing land. In Gerado catchment, northeastern Ethiopia, Asmamaw & Mohammed (2013) observed changes for clay, SOM and total N following changes in land use and land cover. Eyayu et al. (2009) reported declining pH value and the content of SOM in leached and degraded cultivated land than forestland in the Tara Gedam catchment and the adjacent agro-ecosystems of north western Ethiopia. Emiru & Gebrekidan (2013) indicated deforestation has resulted in deterioration of SOM in the soil. Similarly, Tesfahunegn (2013) showed that soil quality indicators varied across the land use and soil management systems, among which natural forestland and afforestation protected areas are the most important systems in maintaining soil quality, where as cultivated and marginal lands seriously deteriorated the physical soil system. The same author revealed that soil organic carbon (SOC), pH, total N, available phosphorous (AP) and clay are significantly higher in natural forest and afforestation protected areas. On the other hand, Yeshanew, Zech & Guggenberger (2005) found SOC and total N at 0–20 cm depth remained the same after natural forest conversion into eucalyptus plantation in Munesa, Ethiopia. Fantaw, Ledin & Abdu (2007) in their study in Bale Mountains of Ethiopia found no variation in soil organic carbon content after natural forest converted into grazing land. These conflicting findings suggest that conversion of forestland into cultivated or

grazing land leads to changes of soil physical and chemical properties and degradation of the land is not at all times and in all places applicable. This further suggests the need for empirical inquiry into effects of land use changes on the dynamics of selected soil properties and subsequent degradation of farm household land. To this end, little work was established on the effects of land use on soil properties, which have implications for land degradation and land management strategies in eastern Africa. Natural forest, comprising trees species such as *Podocarpus falcatus* (Zigba), *Olea europaea* (Woyera) and *Rosa abyssinica* (Kega), was selected as the control field against which different soil properties of cultivated and grazing lands were compared to assess the level of land degradation in the Northeastern Wollega, Ethiopia. The interpretation of our results is limited to the current status of some soil parameters such as soil texture, soil pH, TN, CEC, exchangeable cations (Ca^{2+} , Mg^{2+} , K^+ and Na^+), AP, and SOC, due to the fact that there was no documented data on the former land uses.

Materials and methods

Current land use types

We identified and classified the present land use types through surveys in 2012 and 2013 supported by farmers who are assumed knowledgeable about the local land use types by the local community. Accordingly, three major land use categories, namely forestland, grazing land, and cultivated land were identified for the purpose of this study (Table 2.1). Based on the information obtained from the farmers, the present cultivated land and grassland had been under forestland. That, forestland has been converted into cropland and grassland because increasing demand from human population and livestock for agriculture and grazing, respectively.

Soil sampling

The cluster sampling design by Thompson (1991), which later has been applied by Vågen, Winowiecki, Abegaz & Hadgu (2013), Vågen & Winowiecki (2013), and Abegaz, Winowiecki, Vågen, Langan & Smith (2016) was modified and used for this study. The main reason for selecting cluster-sampling technique is that it is suitable when naturally heterogeneous groupings are evident in sampling frame. It allows sampling of elements in each cluster. Additionally, cluster-sampling technique can reduce sampling costs. The studies by Vågen et al. (2013) was on mapping of land degradation prevalence and soil functional properties in Ethiopia; Vågen & Winowiecki (2013) was on mapping of soil organic carbon stocks for spatially explicit assessments of climate change mitigation potential along the Ethio-Kenya highlands; and Abegaz et al. (2016) was on spatial and temporal dynamics of soil organic carbon in landscapes of the upper Blue Nile Basin of the Ethiopian Highlands. In each of these studies, 3 different areas each with $10 \text{ km} \times 10 \text{ km}$ and 16 clusters or tiles have been used. Since our study is on a small catchment to assess the impact of land use differences on selected soil properties, we modified and applied this sampling design to suit to our study area.

Accordingly, three adjacent sites under different land use types (forestland, cultivated land and grazing land) were selected for this study, with similar slope, elevation and aspect in each land use. We established a $1 \text{ km} \times 1 \text{ km}$ cluster (sampling area), and 5 cluster centroids (sampling plots) were stratified into $200 \text{ m} \times 200 \text{ m}$ tiles and their locations within the sampling area were placed systematically (Figure 4.1). The first tile (sampling plot) established first by fixing its central point at the center of $1 \text{ km} \times 1 \text{ km}$ area. Then, the area of this sampling plot was established using 100 m radius from the cluster center (sampling area) point. The centers of the other four sampling plots were established at 300 m distance from the center of this sampling

plot (the central plot) to north, east, south, and west. The area of each of these sampling plots was established using 100 m radius from their center point. Thus, a 100 m buffered area exists from the boarder of the sampling area and between the neighboring sampling plots. Within each tile four subplots were randomly established, each with an area of 100 m², one in the center and three on a radial arm with 120° angles between them (Vågen & Winowiecki, 2013; Vågen et al., 2013; Assefa et al., 2016). This form of sampling allows the assessment of variability of soil properties at different spatial scales (Vågen et al., 2013) (in our case among land uses at site level). For each tile, soil samples (0-15 cm depth, the average plough layer in the area) were collected from the center of each sub-plot and composite samples were prepared by hand mixing. Totally, we prepared 15 composite soils.

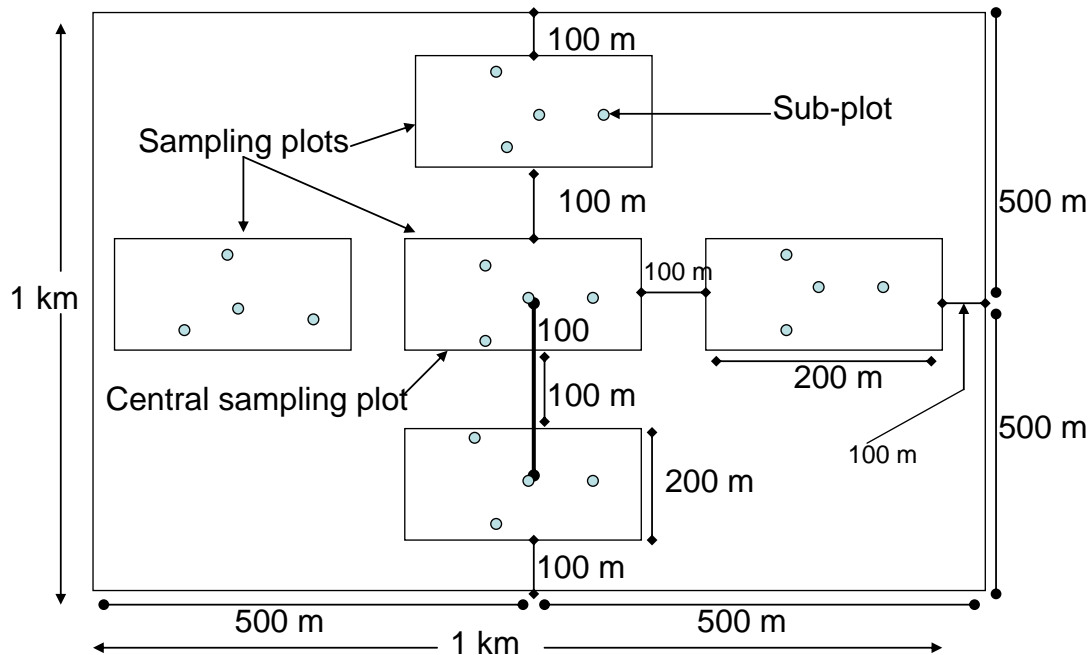


Figure 4.1. Adapted sampling design of soil samples in the Northeastern Wollega, Ethiopia (after Vågen and Winowiecki (2013), Vågen et al. (2013) and Assefa et al. (2016)).

Soil analysis

Composite soil samples were air-dried and grounded to pass through a 2 mm sieve prior to laboratory analysis. Soil analysis included soil texture (determined by Bouyoucos Hydrometer

Method; Black, Evans, White, Newsmonger & Clarkem,1965), soil pH (determined in a 1:2.5 soil: water ratio), total N content, cation exchange capacity (CEC) and exchangeable cations (Ca^{2+} , Mg^{2+} , K^+ and Na^+) by atomic absorption spectrophotometry, AP (Olsen, Cole, Watanabe & Dean, 1954) and organic carbon (OC) content (Walkley & Black, 1934). Soil organic matter (SOM) content (%) was determined by multiplying OC% by 2.0 factors.

Statistical analysis

One-way ANOVA was used to analyze the differences in soil texture, pH, available P, SOM, N-Kjeldahl, CEC and exchangeable cations of the three land use types by collecting 15 composite soil samples (five each from each land use) at the 0.05 level.

Equation 4.1 computed percentage changes in the soil properties of cultivated land or grazing land compared to forestland (ChCl, GI).

$$Ch_{Cl,Gr} = \frac{Lu_{Cl,orGI} - Lu_{Fl}}{Lu_{Fl}} \times 100 \quad (4.1)$$

Where $Ch_{Cl,GI}$ is the percentage changes in soil property of cultivated or grazing lands compared to forestland and Lu_{Cl} , Lu_{GI} and Lu_{Fl} are mean values of soil property under consideration of cultivated, grazing and forestland respectively. Bivariate correlation analysis was conducted to assess the relationships between the studied soil properties.

Results and discussion

Particle size distribution

Sand content of soils of forestland is the highest and the lowest on soils of cultivated land (Table 4.1). These differences are statistically significant ($P < 0.05$, Table 4.3). The percentage change in the distributions of sand particle is higher in cultivated land than the change in grazing land compared to forestland (Table 4.3). Clay content of soils is the highest on cultivated land

and the lowest on soils of forestland (Table 4.1). Clay fraction on cultivated land and grazing land increased compared to forestland; but the change is higher in cultivated land than grazing land (Table 4.3). Lower content of sand and higher content of clay fractions in the cultivated land may be attributed to the process of plowing, clearing, disposing and leveling of farming fields. Because the clay particles are very small, silt and sand fractions could be removed by runoff from the cultivated land. These are deposited on topsoil of forestland and grazing land (Biro et al., 2013). Differences in clay content of soil influence the levels of microbial biomass. These assumed to hold much more water and plant nutrients than forest and grazing lands (Kartul et al., 2013). Soils with high clay content have sufficient particle-to-particle contact points to form strong bonds when the soil dries (Eyayu et al., 2009). Cultivated land with highest clay fraction has the most compact soils.

Soil organic matter, total nitrogen and available phosphorous

The content of SOM was the highest in forestlands and the lowest in cultivated land (Table 4.1), and the differences are statistically significant (Table 4.3). Compared to forestland, percentage change in SOM is higher in cultivated land than the change in grazing land (Table 4.3). The more rapid decrease of SOM contents in cultivated land may be attributed to accelerated rates of erosion and decomposition, because these processes were most active on cultivated lands than forest and grazing lands (Assefa et al., 2016). On the other hand, the reduction is lesser on grazing land because grass roots were fibrous near the soil surface and easily decompose and increasing organic matter. Land management such as poorly designed terracing and cut-off drainage that practiced on the cultivated land facilitated the drainage of water and soil from cultivated land and deposited over forestland (Assefa & van Keulen, 2009).

Table 4.1: Mean variation and standard deviation (SD) of soil fraction, organic matter, total nitrogen, C:N ratio and available phosphorous at 0-15cm depth at different land use types in the Northeastern Wollega, Ethiopia

Land use type	Soil fraction (%)						Organic matter (%)		Total nitrogen (%)		C:N ratio		Available phosphorus (PPM)	
	Sand		Silt		Clay		Mean	SD	Mean	SD	Mean	SD	Mean	SD
	Mean	SD	Mean	SD	Mean	SD								
Forestland	51.6 ^a	3.6	32.8 ^c	1.1	15.6 ^a	2.6	9.0 ^{a,c}	1.3	0.4 ^{a,c}	0.1	12.1 ^c	0.4	3.6 ^{b,c}	1.0
Grazing land	38.4 ^a	1.7	26.8 ^c	10.8	34.8 ^c	10.6	7.3 ^{a,b,c}	1.5	0.4 ^{a,b,c}	0.1	11.9 ^c	3.8	2.1 ^b	0.4
Cropland	29.6 ^a	5.4	28.4 ^c	4.56	42.0 ^{a,c}	6.6	4.6 ^{a,b}	0.7	0.3 ^{a,b}	0.1	10.8 ^c	1.9	3.7 ^{b,c}	1.5

Note:^{a,b} the mean differences of soil properties along each column is significant at P<0.01 and 0.05 levels respectively; ^cthe mean difference is not significant.

Table 4.2: Mean variation and standard deviation (SD) of soil acidity (pH), cation exchange capacity (CEC), exchangeable bases (K⁺, Ca²⁺ and Mg²⁺) at 0-15cm depth at different land use types in the Northeastern Wollega, Ethiopia

Land use type	pH (1:2.5 H ₂ O)		CEC Cmol(+)/kg		K ⁺ Mean	SD	Exchangeable bases Cmol(+)/kg			
	Mean	SD	Mean	SD			Ca ²⁺		Mg ²⁺	
					Mean	SD	Mean	SD	Mean	SD
Forestland	6.1 ^{a,b}	0.36	32.85 ^a	4.04	0.13 ^c	0.04	12.81 ^a	4.01	3.96 ^{a,c}	1.21
Grazing land	5.7 ^{c,b}	0.22	25.65 ^{a,b}	3.32	0.12 ^c	0.07	5.98 ^{a,c}	1.34	4.80 ^{a,c}	1.10
Cultivated land	5.4 ^{a,c}	0.13	20.19 ^{a,b}	3.66	0.14 ^c	0.08	4.08 ^c	1.79	1.71 ^a	0.27

Note: ^{a,b} the mean differences of soil properties along each column is significant at P<0.01 and 0.05 levels respectively; ^c the mean difference is not significant.

Farming system in the area, which is heavily dependent on traditional practices, also facilitates removal of top soil on the cultivated land. This suggests that SOM shows strong response to land use and land degradation (Vågen & Winowiecki, 2013). Thus, the highest SOM in forestland is potentially the highest reservoir for plant essential nutrients of nitrogen, phosphorus, and sulfur (Zeng, Hu, Chang & Fan, 2015). It also increases soil water holding and CEC and enhances soil aggregation and structure of soils of forestland.

Expectedly, the mean value of total N was highest on soils of forestland and lowest on cultivated land (Table 4.1). The change in total N is higher in cultivated land than the change in grazing land compared to forestland (Table 4.3). The C: N ratio was the highest on soils of forestland while it is the lowest on grazing land (Table 4.1). Due to the close relationship between SOM and total N, soil C: N ratio indicates the status of soil fertility. C: N ratio is often influenced by climate, soil condition, vegetation type and agricultural management practices (Ouedraogo, Mando & Stroosnijder, 2006; Zhang et al., 2009). The content of available P was the highest in cultivated land and lowest in grazing land (Table 4.1). The mean differences between soil available P of forest and grazing lands, and cultivated and grazing lands are statistically significant ($P < 0.05$, Table 4.3), while the mean difference between forest and cultivated lands is not statistically significant. Compared to the available P contents of forestland, available P of cultivated and grazing lands has increased (Table 4.3).

Secondary minerals, organic and inorganic fertilizer are important pools of soil phosphorous (P) (Assefa & van Keulen, 2009). Thus, the fact that soils in the forestland has higher available P than the grazing land may be attributed to two reasons. Firstly, even though, in forestland, trees could remove a pool of available P, there is a probability of P return through litter fall to soil surface (Asmamaw & Mohammed, 2013). Secondly, microbes, which are

abundant in the litter layers of the forest, may quickly add high proportion of P pool under forest cover. On the other hand, a higher AP in cultivated land than grazing land may be attributed to three reasons. Firstly, applied cattle dung on cultivated field may increase level of P concentration in this land use, while cattle dung has been collected from grazing land (Table 2.1). Secondly, frequent application of inorganic P-fertilizer on the cultivated fields (Table 2.1) may provide a considerable amount of inorganic P pool to the soil of cultivated filed. Thirdly, a higher P release as a result of higher weathering process on cultivated land than on grazing land may provide higher amount of available P to the soil of cultivated land. This is because of repetitive plowing to prepare the plot for cereal crop production. The finding in this study appeared in agreement with the observation made in Ethiopia by Fantaw & Abdu (2011).

Table 4.3: Percentage changes in selected soil properties on cultivated and grazing land uses compared to forestland in Northeastern Wollega, Ethiopia.

LU Type	Sand	Silt	Clay	pH	AP	OM	TN	CEC	EK ⁺	Eca ²⁺	EMg ²⁺
Cropland	-43	-13	+169	-11.5	+2.8	-49	-43	-38.5	+7.7	-68	-56.8
Grassland	-26	-18	+123	-6.6	-42	-19	-16	-22	-7.7	-54	+21.2

Notes: LU= land use, EK⁺= exchangeable K⁺, Eca²⁺=exchangeable Ca²⁺, EMg²⁺= exchangeable Mg²⁺, - indicates loss and + indicates gains

Acidity, cation exchange capacity and exchangeable basic cations

The soils in the study land uses have a mean pH between 5.4 and 6.1 (Table 4.2). Mean pH from forest soils was statistically different from the cultivated and grazing land ($P < 0.05$, Table 4.3). Compared to the pH of soils of forestland, pH of soils of cultivated and grazing lands were lower (Table 4.3). Thus, soils in the cultivated land appeared more acidic than soils of forest and grazing lands. This is expected where 13.2% of Ethiopian soils are strongly to

moderately acidic ($\text{pH} < 5.5$) (Ermias, Shimelis, Laing & Fentahun, 2013). This is because of intensive farming over a number of years with nitrogen fertilizers on cultivated land. Soil acidity is also a consequence of leaching of basic cations in soils due to high rainfall that have rapid erosion. Cultivated land is characterized by acidifying effects of acid forming nitrogen fertilizer, poor nutrient cycling and mining of basic cations through harvested crops, soil erosion and acid rain, which contribute for development of soil acidity. Soil acidity affects the process of other nutrient transformations, solubility, or plant availability of many plant essential nutrients (Barua & Haque, 2013). In acid soils ($\text{pH} < 6$), nitrification will be slow, and plants with the ability to take up NH_4^+ may have an advantage (Parras-Alcántara, Martín-Carrillo & Lozano-García, 2013). Thus, in the study area, nitrification will be slow in cultivated land pertaining to the acidity of soil. Acid soils affect the quantity, activity, and types of microorganisms in soils which in turn influence decomposition of organic materials (de Mulenaere et al., 2014; Emiru & Gebrekidan, 2013). Acid soil prone areas are characterized by aluminum and manganese toxic to crops growth, constrained productivity through stunted growth, poor response to applied fertilizer and vulnerability to drought. In Ethiopia, soil management strategies such as application of mineral fertilizers, lime, compost and manure are used to ameliorate soil acidity. Soil liming can increase soil pH, supply essential plant nutrients (exchangeable Ca^{2+} and Mg^{2+}), make other essential nutrients more available and prevent Mn and Al from being toxic to plant growth (Yao et al., 2010).

The mean CEC was highest on forestland and the lowest on cultivated land (Table 4.2); and the differences among the land uses are statistically significant ($P < 0.05$, Table 4.3). Compared to the CEC of soils of forestland, CEC of soils of cultivated and grazing lands were decreased (Table 4.3). Mean exchangeable Ca^{2+} content was highest on forestland and lowest on

cultivated land (Table 4.2). The mean differences between forest and cultivated lands, and forest and grazing lands are statistically significant ($P < 0.05$, Table 4.3). The mean exchangeable Mg^{2+} was highest on grazing land and the lowest on cultivated land (Table 4.2). Exchangeable Ca^{2+} was highest in forestland and lowest in cultivated land (Table 4.2). Compared to soils of forest land, the overall pattern of CEC, exchangeable Ca^{2+} and Mg^{2+} concentrations on cultivated land showed declining trends, however with varying rates (Table 4.3). Exchangeable Ca^{2+} showed the highest decline, followed by exchangeable Mg^{2+} and CEC (Table 4.3).

Relationships between selected soil properties

Each of SOM, TN, CEC, exchangeable Ca^{2+} and Mg^{2+} , and pH are positively and significantly ($P < 0.05$, Table 4.4) associated with each of soil properties except with available P, silt and clay. In contrast, clay fraction is negatively and significantly ($P < 0.05$) associated with OM, total N, CEC, exchangeable Ca^{2+} , pH, and silt. SOM significantly and strongly associated with pH. This finding was in agreement with other studies made in different places of the country (e.g., Amare, Terefe, Silasie, Yitaferu, Wolfgramm & Hurni, 2013; Asmamaw & Mohammed, 2013; Lelissa, Hager & Sieghardt, 2010). Thus, conversion of forestland into cultivated lands implies degradation of SOM. Since SOM is the major influences N in the soil, soil available P and CEC, it provides micronutrients through an effective soil food web. However, SOM in soils of cultivated land can be increased through compost, cover crops, manures, minimum tillage and crop rotation (Mikha et al., 2005; Martins, Cora, Jorge & Marcelo, 2009). These can improve the concentration of physical, chemical and biological soil parameters in the cultivated land.

There is no significant correlation between available P and any of the other chemical properties most probably due to the generally low available potassium content and limited range

of pH in the soil sampled. This finding contradicts the fact that phosphorus availability is related to soil pH. CEC significantly and strongly associated with exchangeable Ca^{2+} , pH and clay; exchangeable Ca^{2+} significantly and strongly associated with pH and clay. This shows the ability of CEC to retain cations and the dependency of CEC upon the pH of the soil, soil nutrient retention capacity and the capacity to protect ground water from cation contamination. Exchangeable Mg^{2+} is significantly and strongly associated with pH. On the other hand, clay is negatively correlated with all soil properties. The correlation was strong and statistically significant except for exchangeable Mg^{2+} and AP. Thus, clay in the soil has negative influence on most of soil properties. This suggests that both chemical and physical properties of soils are regulated by clay properties of soil. Fantaw & Abdu (2011) and Lelissa et al. (2010) observed similar relationship.

Table 4.4: The correlation matrix for selected soil properties at 0-15 cm depth in Northeastern Wollega, Ethiopia

	OM	TN	CEC	Ca^{2+}	Mg^{2+}	pH	Silt
TN	0.80**						
CEC	0.80**	0.81**					
Ca^{2+}	0.82**	0.76**	0.89**				
Mg^{2+}	0.71**	0.67**	0.65**	0.52*			
pH	0.83**	0.76**	0.89**	0.88**	0.71**		
Clay	-0.74**	-0.54*	-0.77**	-0.74**	-0.32	-0.71**	-0.69**

** , * Correlations are significant at the 0.01 level and at the 0.05 level respectively, (2-tailed).

Conclusion

The purpose of our study was to explore the effects of land use types on the mean differences of soil properties and its implications for land degradation. The result indicate that cultivated land has the lowest organic matter, total nitrogen, cation exchange capacity, pH,

exchangeable Ca^{2+} and Mg^{2+} contents compared to forestland and grazing land. Soil organic matter is lowest as caused by land use changes, cropping pattern and frequency, removal of crop residues, faster decomposition and oxidation process as well as soil erosion on cultivated lands. The losses of these essential elements may contribute to increasing degradation prevalence on cultivated land. Land degradation, in turn, is impairing the capacity of land to contribute to food security. To increase soil organic matter and consequently enhancing the concentration of other nutrients in the soil of cultivated land, we suggest implementation of integrated land management practices such as compost, cover crops, manures, minimum tillage and crop rotation. Soils in the cultivated land appeared more acidic ($\text{pH} < 5.5$) than those of the forest and grazing lands. This may lead to aluminum, manganese toxicity, microbial conversion of NH_4^+ to nitrate will be slow, and crops with the ability to take up nitrate (NO_3^-) will be negatively affected. Thus, we suggest liming of cultivated land to increase soil pH, supply essential plant nutrients (Ca^{2+} and Mg^{2+}), make other essential nutrients more available and prevent Mn and Al^{3+} from being toxic to crop growth.

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**Effects of Soil Depth on Variations of Soil Properties Under Different Land Use Types in
the Northeastern Wollega, Ethiopia**

Alemayehu adugna and Assefa abegaz

Effects of Soil Depth on Variation of Soil Properties Under Different Land Use Types in the Northeastern Wollega, Ethiopia

Abstract

In the highlands of Ethiopia, degradation of soil resource is among the serious problems related to intensive farming, deforestation and over grazing. This study was conducted with an aim to analyze the variation of selected soil properties at topsoil and subsoil under four land use patterns: forestland, grazing land, cultivated land and shrub land, in Northeastern Wollega, Ethiopia. Soil samples were collected from the land uses at two depths (0-15 and 15-30cm) in replicates and totally 40 composite soil samples were collected. Statistical analysis revealed significant variation in soil properties along soil depth with selected land uses. Topsoil layer had significantly greater organic matter (9.0, 7.3, and 4.69%, respectively, in forestland, grassland and cultivated land), total nitrogen (0.44, 0.37 and 0.25%, respectively, in forestland, grassland and cultivated land), phosphorous (3.60, 2.09 and 3.70 ppm, respectively, in forestland, grassland and cultivated land) than the subsoil organic matter (4.15, 3.67, and 3.43%, respectively, in forestland, grassland and cultivated land), total nitrogen (0.21, 0.20 and 0.19%, respectively, in forestland, grassland and cultivated land), phosphorous (1.84, 1.39 and 1.52 ppm, respectively, in forestland, grassland and cultivated land). However, clay under all land uses and cation exchange capacity under shrub land and grazing land revealed reverse trends. Organic matter and cation exchange capacity have stronger correlations with most of soil properties in the topsoil than in the subsoil while clay has no significant correlation with selected soil properties except with sand fraction in the sampled depths. Hence, the correlation among the selected soil properties also varies with soil depth. In general, the spatial variability of soil properties indicates that they were strongly affected by external factors (agricultural treatments and soil management practices) and internal factor (soil depth).

Key words: CEC; organic matter; soil depth; soil properties

Introduction

In tropical and subtropical highlands, soils are highly weathered, well drained and low in the availability of major soil nutrients, especially total N and available P (Assefa & van Keulen, 2009). As the interface between natural and anthropogenic management system persists, soil undergoes vertical exchange of materials which in turn resulting in physical and chemical changes from topsoil to subsoil (Brady & Weil, 1999). The reasons for these are addition of

organic matter from plant growth to the topsoil, weathering of rocks and minerals, decomposition of organic matter, and translocation of soluble components by leaching, which in turn responsible for the differentiation of soil layers (Foth, 1990). Human management system such as frequent plowing and tillage for the purpose of cultivation, grazing or similar uses also changes the proportions of many soil properties with changing depths (MacCarthy, Agyare, Vlek & Adiku, 2013). Ali, Saheed, Kubota, Masunaga & Wakatsuki (1997) have reported that soil weathering differentials between the soil profiles have caused changes in clay, CEC, organic matter and exchangeable K^+ . Islam & Weil (2000) stated that tillage mechanically disintegrates soil particles and modifies soil conditions for plant growth and intensive leaching, and hastens organic matter decomposition. In Kobamo basin of Nigeria, Abubakar (1997) has studied vertical distribution of soil nutrients along different land use types and reported that sand content of both topsoil and subsoil is higher in cultivated land than the contents in forestland. However, silt and clay fractions are higher in forestland than the contents in cultivated land in both depths. It has also been reported that various nutrient elements such as total N, available P, exchangeable Ca^{2+} , Mg^{2+} and K^+ showed 3 to 43% declining trend as soil depth increases. Duguma, Hager & Sieghardt (2010) also reported that OC, total N and available P declined with depth for cereal farm; but these nutrients increased by 48.1, 63.4 and 20.4%, respectively across the depth in the pasture land. Exchangeable cations decreased with depth except exchangeable Ca^{2+} in wood lots, exchangeable K^+ in homesteads and Na^+ in cereal farms. CEC, however, decreased in all the land uses with depth by about 19% (Duguma et al., 2010).

The associations among the soil properties also vary with the variation of depth. In topsoil, CEC is strongly associated with organic matter than clay (McAlister, Smith & Sanchez, 1998). In the subsoil, since there is higher clay and relatively lower OM, CEC was strongly

correlated with clay than OM (Jin, Ye, Xu, Shen & Huang, 2011). These observations supported the thought that soil properties react to depths across the various land use types. In the northeast Wollega, each year approximately 1.5% of forestland was converted to other land covers. In comparison, 85% of the loss goes to agricultural land that has been cultivated for years. This change has been linked to tree mortality and mineral mining. The size of agricultural land expands further, because of uncontrolled farming and settlement distributions. In addition, there study that examines dynamics of soil properties with depth at different land uses is not available at the site. On the other hand, understanding the effects of soil depth on the dynamics of soil properties under different land use is essential to establish appropriate management options aimed at sustaining soil health and restoring degraded soils. Therefore, the objective of this study was to examine the effects of soil depth on some selected soil properties and identify the relationship between soil properties in topsoil and subsoil layers.

Materials and methods

Soil sampling

Four adjacent sites were selected in this study, each located within the four different land use types, representing forestland, cultivated land, grazing land and shrub land (Table 2.1). Each land use has been divided into five tiles (100×100 m in size). Within each tile four sub-plots were established, each with an area of 100 m^2 , one in the center and three on a radial arm with 120° angles between them (Vågen, Winowiecki, Abegaz & Hadgu, 2013). This form of sampling allows the assessment of variability of soil properties at different spatial scales (in our case soil property variation at top and sub-soils among land use differences at site level).

Soil sampling was carried out in February 2014 from each of the four land use types. At every sampling plot, soil samples were collected from five spots (center, north, south, east and

west from the center of the plot) within the land use and composite samples were prepared by hand mixing depending on depth strata. The center of the sub-plot has been fixed at intersection point of a north-south and east-west bisecting lines of the sub-plot (each 5 m inward from north, east, south and west border of the sub-plot). Each of the other four points are fixed at 2.5 m distance from this central point to the north, east, south and west (Figure 4.1). In each sub-plot, these five sampling points are considered to capture micro-spatial variability. Totally, we had 40 composite soil samples. For every land use plots, soil samples were taken at two depths: 0-15 cm (topsoil layer) and 15-30 cm (subsoil layer) using soil auger. The two depths are deliberately chosen for two main reasons. Firstly, the 0-15 cm represents the average plough layer in the area while the 15-30cm depth is the layer where the clay particles leached from the topsoil accumulate. Secondly, samplings at these predetermined depths enhance comparability of soil properties with depth among the studied land uses.

Soil Analysis

Composite soil samples were air-dried and grounded to pass through a 2mm sieve prior to any laboratory analysis. Soil analysis included soil texture (determined by Bouyoucos Hydrometer Method; Black, Evans & Dinauer, 1965), soil pH (determined in a 1:2.5 soil: water ratio), total N content(N-Kjeldahl procedure), cation exchange capacity (CEC) and exchangeable cations (Ca^{2+} , Mg^{2+} , K^{+} and Na^{+}) by atomic absorption spectrophotometry, available P content (Olsen, Cole, Watanabe & Dean, 1954) and organic carbon (OC) content (Walkley & Black, 1934). Soil organic matter (SOM) content (%) was determined by multiplying OC% by 2.0 factors.

Statistical analysis

The data was organized and entered into Statistical Package for Social Sciences (SPSS) software version 20.0 for windows. Independent samples t-test was under taken to test the significance of the effects of soil depth, along with the impact of land use differences, on the variation of soil textural class, soil acidity, available P, soil organic matter content (%), total Nitrogen (%), CEC Cmol kg^{-1} , and Exchangeable bases (K^+ , Ca^{2+} , and Mg^{2+}) Cmol kg^{-1} at the 0.05 level. The independent variable (i.e. soil depth) has two groups: topsoil (0-15 cm) and subsoil (15-30cm). Independent samples t-test was used in this study because the data meet the six different assumptions of independent t-test such as measurement at interval level, two category of independent variables, independence of observations, absence of outliers, normal distributions of independent variable and homogeneity of variance. Bivariate correlation analysis was conducted to assess the relationships between the studied soil properties. Variation in soil properties with depth across the land use types were computed by taking the topsoil as reference groups. Hence, for a given soil property, the variation expresses how much it increased or decreased in percent in relation to the reference group (Equation 5.1).

$$R_{SUB} \% = \frac{Q2 - Q1}{Q1} \times 100 \quad 5.1$$

Where, R_{sub} =Variation in % of soil properties in subsoil layer compared to topsoil properties

Q1= value of soil property in the topsoil layer

Q2=value of soil property in the subsoil layer

Results and discussion

Particle size distributions

The proportion of sand fraction was highest on the shrub-land and lowest on the cultivated-land, both in the topsoil and subsoil (Table 5.1). Silt was highest on the forestland and lowest on the shrub-land, both in topsoil and subsoil. Clay was highest on the cultivated-land and lowest on the shrub-land in both soil layers (Table 5.1). The highest and the lowest values, respectively, of sand and clay fractions in topsoil of shrub-land might have been attributed to relatively higher rate of down ward drain of clay in the topsoil (Siddique et al., 2014) and slow rate of weathering process. Shrub-land has unstable soil fractions because of steeper slope and over grazing (Table 2.1). This finding contradicts with the result of Abubakar's (1997) study that reported sand content was the highest in the cultivated-land and the lowest in forestland for both topsoil and subsoil.

It was clear that the sand particle decreased as soil depth increased at all land-use types. The change was highest in forestland and lowest in cultivated-land (Figure 5.1). On the other hand, clay particle increased as soil depth increased at all land-use types. The change was the highest in forestland and the lowest in cultivated-land (Figure 5.1). This finding revealed that soil particles significantly changes as soil depth increase at varying rates. These variations might be caused by variation of land-use overlying the surfaces overlying the plots from where soil samples were collected. Studies in Ethiopia (e.g., Eyayu, Heluf, Tekalign & Mohammed, 2009; Yimer & Abdelkadir, 2011; Asmamaw & Mohammed, 2013) and in Nigeria (Abubakar, 1997) on spatial variability of soil properties have shown similar changes.

Organic matter and total N

Both OM and total N was highest on the forestland and lowest on the shrub-land, both in the topsoil and subsoil and decreased as soil depth increased at all land-use types (Table 5.1).

The change was highest on the forestland and lowest on the cultivated-land (Figure 5.1). This implies that forestland has the most biologically active surface soil layer (Yimer & Abdelkadir, 2011). The litter on the soil surface beneath different canopy layers and high biomass production caused high biological activity in this layer. The continuous accumulation of un-decayed and partially decomposed plant and animal residues results in high rate of interception and infiltration and subsequent reduction of erosion (Morgan, 2005).

However, the possible explanation for the decrease of organic matter with increasing soil depth on cultivated-land may be due to the prevalence of active erosion, decomposition process and disturbances by tillage. Tillage results into rapid decomposition of soil organic matter and reduce the contribution of organic and microbial process to nutrient cycling by combining different soil layers (Abera & Belachew, 2010; Bhuyan, Tripathi & Khan, 2013). Furthermore, the lowest change of total N under cultivated-land implies that fertilizer applications may not have replaced the N lost due to harvest removal, leaching, and humus losses associated with cultivation (Eyayu et al., 2009). Farmyard manures and organic matter from which total N for crop production synthesized and mineralized in cultivated land is low. Dung and urine from animals concentrated in stock camps, under trees and near gateways. As informed by elders, this system is used to restock N in the soil that lost due to crop harvest. Thus, cultivated land often supplied with soluble form of nitrogen, namely nitrate (NO_3), or ammonium (NH_4). This could be attained directly by adding fertilizers such as urea and Diammonium phosphate (DAP) to enhance agricultural productivity.

Table 5. 1: Soil properties at topsoil and subsoil at different land use types in the Northeastern Wollega, Ethiopia

Land use type	Depth (cm)	Soil fraction (%)			Organic	Total	AP	C:N	CEC	Exchangeable bases			pH (1:2.5
		Sand	Silt	Clay	Matter (%)	Nitrogen (%)	(PPM)	Ratio	Cmol(+)/Kg	Cmol (+)/Kg	K ⁺	Ca ²⁺	Mg ²⁺
FL	0-15	51.6	32.8	15.6	9.04	0.44	3.60	12.1	32.85	0.13	12.81	3.96	6.1
	15-30	35.6	28.0	36.4	4.15	0.21	1.84	11.6	22.54	0.06	8.13	3.02	5.9
BL	0-15	73.6	12.8	13.6	2.79	0.14	1.49	12.0	7.37	0.03	0.54	0.55	5.4
	15-30	62.8	14.4	22.8	2.03	0.11	0.76	11.0	8.68	0.02	0.34	0.12	5.2
GL	0-15	38.4	26.8	34.8	7.31	0.37	2.09	11.9	25.65	0.12	5.98	4.80	5.7
	15-30	27.6	24.8	47.6	3.67	0.20	1.39	10.5	26.93	0.05	4.10	3.23	5.6
CL	0-15	29.6	28.4	42.0	4.59	0.25	3.70	10.8	20.19	0.14	4.08	1.71	5.4
	15-30	26.8	26.4	46.8	3.43	0.19	1.52	10.7	17.19	0.12	3.38	1.66	5.4

Note:
FL= Forestland,

CL=Cultivated Land, GL=Grazing Land, BL=Bush Land, AP=Available Phosphorous, C: N= Carbon: Nitrogen ratio, CEC=Cation Exchangeable Capacity, K⁺= Potassium, Ca²⁺= Calcium, Mg²⁺=Magnesium,

Available P

Available P was highest on the cultivated-land and lowest on the shrub-land in topsoil depths. In the subsoil depth, available P was highest on the forestland and is the one, which exist in low proportions (Table 5.1). This was found probably due to the deficiency of the soil to retain phosphorous since soils are acidic and clayey; its deficiency may be attributed to human management systems such as deforestation, overgrazing, over cultivation and erosion, which in turn, reveals the prevalence of land degradation (Brady & Weil, 1999). According to Tisdale, Nelson, Beaton & Havlin (1993) crops require concentration of available P greater than 8 ppm. Hence, available P was below the requirements even for the low demanding crops in the study area. Available P decreased as soil depth increased at all land-use types and was highest on the cultivated-land and lowest on the grazing-land (Figure 5.1). The highest decrease in available P on the cultivated-land is most likely to appear due to the surface of the cultivated land is continuously supplied with inorganic fertilizer and removed by annual crops. This suggested that cultivated-land should be supplied with inorganic fertilizer to increase the concentration of available P in the soil that required by crops. This finding also corroborates the reports of similar and recent studies (Abera & Belachew, 2010).

Cation Exchange Capacity and Exchangeable basic cations (K^+ , Ca^{2+} and Mg^{2+})

CEC was highest on the forestland and grazing-land, respectively in the topsoil and subsoil, and lowest on the shrub-land (Table 5.1). CEC increased with soil depth for the forestland and cultivated-land uses (Figure 5.1). This is because of the presence of higher OM on the surfaces of forestland and available P in the cultivated land. SOM influences the abundance of CEC in the soils (Adeboye, Bala, Osunde, Uzoma, Odofin & Lawal, 2011). Inversely, CEC decreased with soil depth for both shrub-land and grazing-land uses (Figure 5.1). Clay content

may influence the abundance of CEC in the soils of these land uses. The variability of CEC with depth among different land uses imply the difference in the ability of the soil to hold positively charged ions affecting the stability of soil structure, nutrient availability, soil pH and soil's response to fertilizers (Crewett, Bogale & Korf, 2008). This finding is also supported by McAlister et al. (1998) who justified that CEC of soils varies with the changes of clay percentage, the type of clay, soil pH and amount of organic matter.

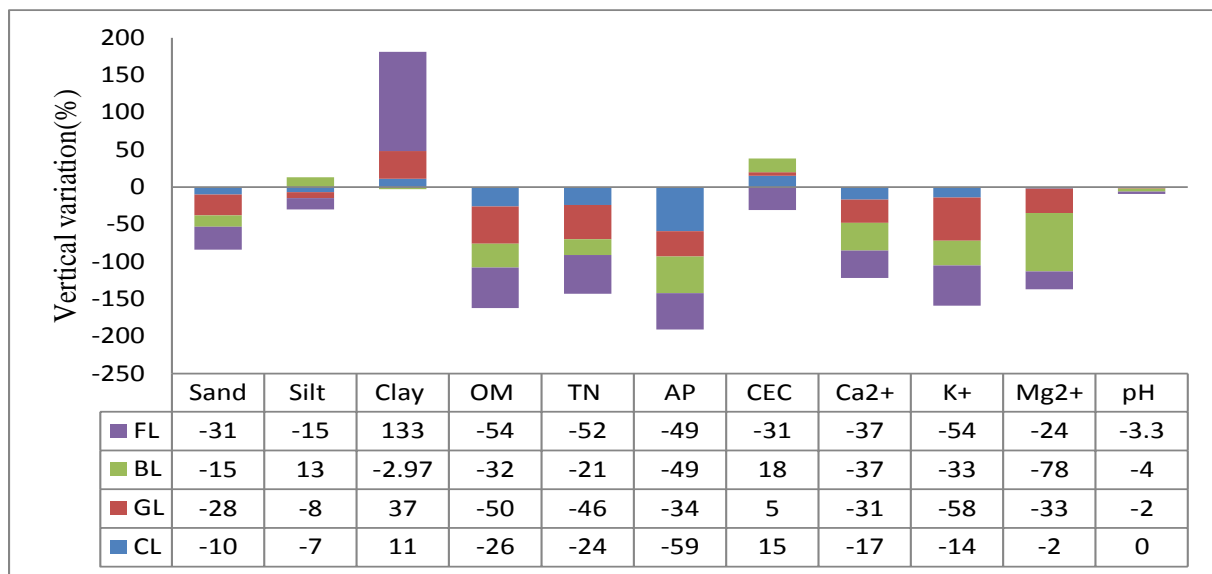


Figure 5.1. Variation (%) in soil properties between subsoil and topsoil depth compared to values of topsoil in northeastern Wollega, Ethiopia

Exchangeable K^+ and Ca^{2+} were highest on the cultivated-land and lowest on the shrub-land in both soil layers (Table 5.1). Mg^{2+} was highest on the grazing-land and lowest on the shrub-land in both soil layers (Table 5.1). Exchangeable basic cations decreased as soil depth increased at all land use types (Figure 5.1). The highest content of exchangeable K^+ on the cultivated-land in both soil layers may be related to frequent supply of fertilizers i.e. urea and DAP applied to cultivated land. Inversely, the lowest exchangeable K^+ in the shrub-land may be attributed to high browsing, erosive nature of the soil (sandy soil) and high-level erosion. The

highest decrease in exchangeable K^+ as depth increased on the grassland may be attributed to cattle manure supplied to the topsoil.

Exchangeable Ca^{2+} experienced highest decrease as depth increased for both forestland and shrub-land uses, and lowest decrease on the cultivated-land. This may be occurring due to the presence of leaf litters from plant falls, macro fauna and soil micro flora and microbial activities. Exchangeable Mg^{2+} experienced the highest decrease in the shrub-land and the lowest in the cultivated-land. The possible explanation for common declining pattern of exchangeable cations with increasing soil depths could be localized enrichments of cation containing minerals of the parent rock (Korkanc, Ozyuvaci & Hizal, 2008). Exchangeable cations could also be added by outside sources attributed to human management such as through fall, plant and animal residues, chemical fertilizers (on cultivated land), animal manures and wood ashes (Korkanc et al., 2008). In the subsoil, exchangeable cations declined probably due to leaching, decomposition, plant root uptake, runoff and erosion.

The effect of soil depth on correlation of soil properties

Organic matter was significantly positively correlated with most of soil properties except sand and clay in all soil depths (Table 5.2). Expectedly, OM was very highly positively correlated at 0-30cm ($r=0.93$, $P<0.01$) followed by subsoil ($r=0.91$, $P<0.01$) and topsoil ($r=0.90$, $P<0.01$) (Table 5.2). It was very weakly negatively correlated with clay in topsoil ($r=-0.07$) and sand ($r=-0.01$) at 0-30cm, but very weakly positive with clay in subsoil ($r=0.26$). CEC was significantly positively correlated with most of the soil properties at all soil depths except sand. CEC was very highly positively correlated with Mg^{2+} ($r=0.94$, $P<0.01$) in subsoil and with TN ($r=0.91$, $P<0.01$) in topsoil and 0-30cm ($r=0.87$, $P<0.01$). It was very weakly positively correlated with clay in all soil depths. TN was significantly positively correlated with selected

soil parameters except sand in topsoil and subsoil, sand and clay at 0-30cm. The correlation was very highly positive with OM at 0-30cm ($r=0.93$), subsoil ($r=0.91$) and topsoil ($r=0.90$). The correlation of total N with clay is very weakly positive at all soil depths (Table 5.2). Available P was significantly positively correlated with most of the soil properties at all soil depths except sand. The correlation was highly positive with K^+ in topsoil ($r=0.77$) and 0-30cm ($r=0.72$), and with OM ($r=0.63$) in subsoil. Nevertheless, it was very weakly positively correlated with clay in topsoil ($r=0.21$) and subsoil ($r=0.36$), while they were negatively correlated at 0-30cm ($r=-0.04$).

Exchangeable Ca^{2+} was significantly positively correlated with most of the soil parameters, and negatively correlated with sand and clay at both sampling depths (Table 5.2). The correlation was very highly positive with CEC ($r=0.90$) in topsoil. The correlation of exchangeable Ca^{2+} with clay was very weakly positive in the subsoil ($r=0.01$) and negative in topsoil ($r=-0.1$) and at 0-30cm depth ($r=-0.1$). Exchangeable Mg^{2+} was significantly correlated with most of the selected soil properties at all soil depths except sand. The correlation, however, was negative with sand and clay at both sampling depths. Exchangeable Mg^{2+} was highly positively correlated with OM ($r=0.84$) in topsoil and CEC($r=0.94$) in subsoil and ($r=0.87$) at 0-30cm. Exchangeable Mg^{2+} was, however, very weakly positively correlated with clay at all soil depths.

The correlation matrix shows that OM, CEC and exchangeable Ca^{2+} are fundamental elements since they are significantly correlated with most of soil properties at all soil depths (Assefa & van Keulen, 2009). The negative correlation of most of selected soil properties with clay and sand fraction at soil depths may be attributed to the parent materials from which sand and clay fractions are formed (Thapa & Yila, 2012). Sandy soils are loose, course textured and don't retain moisture. This is because sandy soils are formed from the disintegration and

weathering of rocks such as limestone, granite, quartz and shale (Crewett et al., 2008; Ozcan et al., 2013). The weak correlation between organic matter and clay in the subsoil may be attributed to the opposite pattern in percentage change of organic matter (decreasing) and clay (increasing) in subsoil from the topsoil. In the subsoil, poor drainage, high water logging, poor aeration and workability characterized the soil where crop cultivation could be supported by supplying compost and gypsum (Thapa & Yila, 2012). The decomposition process in the subsoil is slow because of bonds between the surface of clay particles and organic matter. Repetitive tillage, burning of vegetation and biomass production for agricultural production than soil texture influences SOM in the study. This finding corroborates with McCarthy et al. (2013) and McAlister et al. (1998) studies that stated sand and clay are negatively correlated with most of soil properties. The finding of our study, however, contradicts with the fact SOM positively correlated with clay content. The correlation coefficients showed that the relationship between selected soil properties vary with depth.

However, it is difficult to generalize and explain on which soil depths that correlation coefficient of selected soil parameters would be stronger. For instance, organic matter has stronger correlation with most of soil properties, such as CEC, pH, exchangeable Ca^{2+} and Mg^{2+} in the topsoil than in the subsoil. Conversely, it is strongly correlated with total N, exchangeable K^+ and available P at 0-30cm depth. This implies that organic matter is mainly concentrated in the topsoil layer and subjected to a continuous transformation process as soil depth increases. These circumstances have been revealed in other empirical studies (McAlister et al., 1998; McCarthy's et al., 2013), which also showed the influence of SOM on other physico-chemical properties. Similarly, CEC strongly correlated with OM, total N, available P, pH, silt

exchangeable K^+ and Ca^{2+} in the topsoil than subsoil, whereas it has stronger correlation with exchangeable Mg^{2+} , sand and clay in the subsoil than topsoil layer.

Implications of soil variability to land management

Our study presented that most of soil properties deteriorate with soil depth among different land use types. The reason for such deterioration may be land management, which facilitate loss and mining of soil properties. Land management practices such as malconstruction of traditional bunds in the cultivated-land, diverting water flow by constructing small dams and digging canals, unable to nurture drought resistant plants and grass strips on the farm field boundaries, ploughing land along the contour line were identified in the area. These can initiate the transportation of topsoil from cultivated land and deposition on forestland, grassland and shrub-land (Shiferaw, Okello & Reddy, 2009).

Another reason can be the existing land-use system. Population pressure leads to intensive cropping, which reduce the build-up of organic matter in the soil, and expansion of subsistence farming into forestland. Soil organic matter is an important indicator of soil productivity because of its decisive role in soil chemical, physical and biological properties. Low percentage base saturation levels in the subsoil are an important observation in an area where the topsoil is subject to erosion. Fertilizer application would enhance plant growth, but it requires financial input. However, if crop mulches were to be managed efficiently, N availability to the plants would be increased. As pointed out by farmers, large parts of the area had been covered. The early 1970s marked the disappearance of much under pressure forests from the rapidly growing population. Currently, the average land holding size is one hectare, which is cultivated for subsistence. The dominant crops are cereals, such as wheat, barley, maize and *tef*. In the past, most of the seeds were saved from the harvest of the preceding year.

Table 5.2: Correlation for selected soil properties each other in 0-15, 15-30 and 0-30cm depth

Correlation of:	Soil depth	TN	CEC	K ⁺	Ca ²⁺	Mg ²⁺	AP	pH	Sand	Silt	Clay
SOM	0-15	0.90	0.88	0.48	0.89	0.84	0.46	0.79	-0.30	0.65	-0.07
	15-30	0.91	0.82	0.42	0.84	0.79	0.63	0.74	-0.65	0.83	0.26
	0-30	0.93	0.76	0.54	0.82	0.76	0.65	0.68	-0.11	0.59	-0.22
CEC		OM	TN	K	Ca	Mg	AP	pH	Sand	Silt	Clay
	0-15	0.88	0.91	0.58	0.90	0.83	0.57	0.76	-0.52	0.77	0.12
	15-30	0.82	0.81	0.19	0.74	0.94	0.36	0.73	-0.67	0.72	0.36
TN	0-30	0.76	0.79	0.45	0.85	0.87	0.50	0.75	-0.50	0.75	0.14
		OM	CEC	K	Ca	Mg	AP	pH	Sand	Silt	Clay
	0-15	0.90	0.91	0.55	0.86	0.83	0.50	0.73	-0.41	0.61	0.10
AP	15-30	0.91	0.81	0.41	0.70	0.70	0.53	0.65	-0.69	0.80	0.33
	0-30	0.93	0.79	0.58	0.78	0.74	0.66	0.64	-0.20	0.58	-0.11
		OM	TN	CEC	K	Ca	Mg	pH	Sand	Silt	Clay
Ca ²⁺	0-15	0.46	0.50	0.57	0.77	0.59	0.26	0.38	-0.47	0.55	0.21
	15-30	0.63	0.53	0.36	0.47	0.53	0.33	0.42	-0.50	0.36	0.36
	0-30	0.65	0.66	0.50	0.72	0.59	0.34	0.40	-0.20	0.45	-0.04
Mg ²⁺		OM	TN	CEC	K	Mg	AP	pH	Sand	Silt	Clay
	0-15	0.89	0.86	0.90	0.49	0.72	0.59	0.85	-0.24	0.64	-0.14
	15-30	0.84	0.70	0.74	0.23	0.81	0.53	0.93	-0.47	0.75	0.10
	0-30	0.82	0.78	0.85	0.44	0.76	0.59	0.87	-0.23	0.67	-0.13
		OM	TN	CEC	K	Ca	AP	pH	Sand	Silt	Clay
	0-15	0.84	0.83	0.83	0.54	0.72	0.26	0.73	-0.40	0.46	0.18
	15-30	0.79	0.70	0.94	0.09	0.81	0.33	0.77	-0.58	0.72	0.24
	0-30	0.76	0.74	0.87	0.40	0.76	0.34	0.75	-0.37	0.57	0.10

Fertilizers were used in small quantities or not at all, depending on the productivity of land and the financial situation of the farmer. Cow dung was used for manure. Since 1975, however, the system has changed. Seeds are supplied by government agencies or enterprise; fertilizers were used in large quantities regardless of land productivity; cow dung is often used as fuel due to the scarcity of fuel wood. The land was prepared manually by the land-user, often with the help of other villagers. Sometimes, mixed cropping was practiced, mainly for the vegetable crops. No intercropping has been done. Livestock plays a pivotal role in this mixed agricultural system. The cattle were left free on the large grassland and shrubland. In addition, cropland experienced an expansion towards forestland. These could be resulted into forest degradation and mining of soil minerals from cultivated land. This is, to some extent, the result of poverty, limited alternative employment and inadequate technology. In addition, fallowing is abandoned as more land is required for production. Fuel wood is cheaper than alternative forms of fuel. Even if the price of fuel wood were to increase, demand for it would not be drastically reduced due to the unavailability of substitutes. The village has no access to electricity and facilities for using petroleum gas are next to non-existent. This study, therefore, suggests that soil loss from topsoil could be reversed through changing land management and land use systems.

Conclusion

Based on field survey and monitoring data from different land uses, dynamics of soil properties at topsoil and subsoil were studied. Our results revealed that soils of different land uses have experienced dynamicity with increasing soil depth. The correlation among soil properties implies that soil-forming factors manifested in the process of addition, transformation, transfers and losses processes influence intensity of relationships. In general, the findings of this paper suggest that the dynamics of soil properties are attributed to human activities. The

presence of vegetation markedly minimizes the rate of soil reduction from topsoil to subsoil. Vegetation clearance will decrease the thickness of litter layers and then speed up leaching processes. Agricultural production determines in large part the extent to which soil organic matter accessible to transformation, transfer and losses in soils. Therefore, we suggest land use change such as conservation tillage, application of animal manure, adoption of leguminous trees, intercropping and mulch of crops help to control soil loss and improve soil properties.

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**Rural Livelihood Diversification: A Pathway to Adapt with Land Degradation in
Northeastern Wollega, Ethiopia**

Alemayehu Adugna, Assefa Abegaz, Asmamaw Legass and Diogenes L. Antille

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Rural livelihood diversification: a pathway to adapt with land degradation in Northeastern Wollega, Ethiopia

Abstract

In Ethiopia, agriculture is the foundation of livelihood for the majority of rural families. Relatively high reliance on non-diversified agriculture poses a problem to the long-term survival of rural communities and environmental sustainability. The work reported in this article examines the determinants of livelihood diversification among rural households in Northeastern Wollega, Ethiopia. The study was based on primary data obtained from a cross-sectional survey of 200 households randomly selected following a two-stage sampling from five farming communities or villages. The data were collected using structured questionnaires, key informant interviews and group discussions. These were designed to draw data relating to households' socio-economic characteristics, income-generating activities and determinants of agricultural diversification. The data were analyzed using descriptive statistics and a logistic regression model. Results showed that the communities analyzed in this study had an average household size equivalent to seven people, which suggested surplus labor based on a per capita land-holding size of 0.14 hectare. The main factors influencing livelihood diversification in rural households were sex of household head, household size and farm size, and land tenure regime. Male-headed households with larger family size and smaller farm size, and farms where sharecropping is practiced tend to have a relatively greater degree of diversification than their counterparts. Based on this and earlier studies, diversification is likely to increase livelihood security and long-term prosperity. Therefore, agricultural policies aimed at encouraging diversification will likely reduce the vulnerability of rural households, increase farm outputs, income and therefore living standards.

Keywords: *Land degradation, Logistic regression, Rural economy, Sharecropping, Small-holder farmers*

Introduction

In Ethiopia, agriculture is the foundation of the country's economy, accounting for approximately 50% of the gross domestic product (GDP), 85% of exports and 80% of total employment (Geda, Shimeles & Weeks, 2009; Zewdu, Bamlaku & Hanjira, 2014). However, periodic drought, soil degradation caused by overgrazing and removal of natural vegetation coupled with rapid growth of population and inappropriate land tenure regimes pose a significant sustainability challenge to Ethiopia (Matouš, Todo & Mojo, 2013; Lemenih, Kassa, Kassie,

Abebaw & Teka, 2014; Adugna, Abegaz, Legass & Antille, 2016). Yet agricultural land is the country's most valuable resource. In the local context, agriculture has traditionally offered rural communities little opportunities for diversification. In this regard, livelihood diversification is associated with several barriers (Dercon & Christiaensen, 2011). Among these are: small and fragmented land holding, severe soil loss through erosion processes, depleted soil fertility, degraded forest cover and associated ecosystem's function and services, scarcity and inefficient use of water resources, low livestock productivity, declining labor absorption capacity, decelerated productivity, and remoteness and lack of suitable road infrastructure (Kebrom, 1999; Tsegaye, Moe, Vedeld & Aynekulu, 2010; Asmamaw, Mohammed & Lulseged, 2011; Bahir, Ahmed & Antille, 2015). Current land tenure systems mean that poorer households have only access to relatively less productive land compared with wealthier households (Seger, et al., 2010). Such systems can lead to poverty traps and result in structural and persistent poverty (Hanjra, Ferede & Gutta, 2009). The establishment of a fairer land tenure system is required to increase sustainability and rural development (Kumar & Quisumbing, 2012). Households have customary adaptation strategies to overcome these barriers, which serve to manage risk, respond to shocks and enable collective action across-scales (Stringer & Harris, 2014). For example, Khatun & Roy (2012) suggested that these adaptive strategies could be manifested in complementarities between crop and livestock productions. Bowser & Nelson (2012) examined comparative advantages offered by superior technologies, skill or capital endowments as a good strategy to overcome entry barriers of livelihood diversification. Other studies (e.g., Vincent, 2007; Barret, 2008; Quinn, Ziervogel, Taylor, Takama & Thomalla, 2011; Stringer & Harris, 2014) cited endowment in agricultural potentials and infrastructures, market access and proximity to urban centers as opportunities that are essential to sustain rural livelihood. Lama

(2014) related opportunities that determine decision-making about livelihood diversification with educational level, household size, age and sex of household heads, social status, usage of chemical fertilizer and improved seed as well as knowledge of land management practices.

Appropriate policy measures are needed to manage trade-offs, which are indicated by Zewdu et al. (2014) as entry barriers to livelihood diversification. In response to the need for greater diversification, in 1991 the Ethiopian government initiated a substantial structural adjustment program emphasizing on liberalization, participatory governance and development thinking to alleviate frequent food insecurity for households in the degraded highlands in the north of the country, and to ease human pressure on environment (Ayele & Mamo, 2004; Lanckriet et al., 2015). To this end, the government launched an agricultural development-led industrialization strategy known as ADLI, along with development programs aimed at reducing structural poverty. These initiatives included the Sustainable Development and Poverty Reduction Program (2001), Agricultural Growth and Rural Development Strategy (2004), the Food Security (2004), and Growth and Transformation Program (2010), respectively. Livelihood diversification is defined by Ellis (1998) as *“the process by which rural families construct a diverse portfolio of activities and social support capabilities in order to survive and to improve their standards of living”*. Diversification in staple crops and livestock is given precedence because of greater capability to contribute to poverty reduction (Baird & Gray, 2014). However, a progressive and sustained reduction in poverty requires adoption of both traditional and modern technologies (Vermeulen & Cotula, 2010). Given more than 50% of the country’s population live within the food deficit area, an equitable and diversified agricultural growth strategy is required (Holden, Shiferaw & Pender, 2004). This can be attained via agricultural

intensification or/and diversification strategies since both are likely to increase food availability and income levels (Pretty, Toulmin & Williams, 2011).

Our study focuses on livelihood diversification as a means to increase food security and overall wealth. Livelihood diversification in rural households leads to reduced level of risks, particularly when access to credit or insurance markets is not an option readily available (Ellis, 2000). Diversification is widely understood as a form of self-insurance for risk management (Rickard, 2006). Risks are often framed in terms “push” and “pull” factors wherein households facing undesirable circumstances are pushed into livelihood diversification and households reacting to opportunities to reduce future threats are thought to be pulled into livelihood diversification (Baird & Gray, 2014). The adverse circumstances in the area can be manifested in the form of widespread soil degradation, over-grazing of pastures and deforestation. Thus, livelihood diversification can ameliorate the adverse circumstances as households shift from activities based on environmental resources to off-farm or non-farm income producing activities (Nega, Mathijs, Deckers, Haile, Nyssen & Tollens, 2010). In the northeastern part of the country, more than 90% of the population lives from subsistence farming and oxen-plow agriculture is widespread (Bahir et al., 2015). Disadvantaged farmers do not have ready access to high-quality land, which is a clear reflection of socio-economic inequalities in Ethiopia. The poor have to lease from the rich and they have to give up to one-third of their produce in return for the use of the land. The poorest of all farmers can only survive as day laborers. Land inadequate household, therefore, should rent lands in the form of sharecropping arrangement to produce for subsistence. Asymmetrical character of land-rights is known to play a central role in accelerating land degradation processes, which is documented in several studies (e.g., Lanckriet et al., 2015). A study by Liu & Lan (2015) also suggests that rural poverty is closely related to land degradation

because it is both cause and consequence, respectively. Review of adaptation and livelihood status of households elsewhere in Ethiopia showed those that produce more with a wider range of crops and a greater participation in commercialized farming are more successful (Kumasi & Asenso-Okyere, 2011; Biazin & Sterk, 2013; Yami, Mekuria & Hauser, 2013; Lemeneh et al., 2014).

Objectives

The work reported in this article focuses on depicting how “push” and “pull” factors interact to encourage, or otherwise, motive diversification within the local context. There also appears to be a paucity of scientific information regarding changes in the economy and environment of households, and in understanding the dynamism of determinants of diversification in rural communities of Northeastern Wollega. Therefore, the objectives of this study were to: (1) examine the characteristics of rural households in Northeastern Wollega, (2) determine whether livelihood is diversified, and (3) identify determinants of livelihood diversification in Northeastern Wollega, Ethiopia.

Materials and methods

Northeastern Wollega was selected as the survey site due to the prevalence of numerous push and pull factors of livelihood diversification among the rural households, which is highlighted in related studies (e.g., Mada & Menza, 2015). The push factors may include small fragmented land holding, severe soil and water loss by erosion processes, depleted soil fertility, degraded forest, low livestock productivity and lack of suitable road infrastructure. By contrast, pull factors may include labor absorption, educational level, household size, age and sex of household heads, and knowledge of land management practices.

Sampling design

This study was conducted using cross-sectional survey data, which was considered a suitable technique for the purpose of this work (Okere & Shittu, 2013). This technique enabled the characterization of households, including demographic, social and economic aspects as well as examining variables that influence livelihood diversification. A formula used by Amare & Belaineh (2013) was employed in our study to determine the required sample size. Data for the study was collected from 200 sample households dwelling in five farmers associations (*kebeles*). Sample households were selected using a two-stage random sampling technique. In the first stage, five farmers' associations, where threats of land degradation exist, were purposefully selected from 19 based in Northeastern Wollega (Jardaga-Jarte district). These associations were the following: *Sombokumi*, *Sombowato*, *Harolego*, *Iero* and *Tulunono*, respectively. In the second stage, using the fresh household list obtained from each of the farmers' associations sampled, sample households were randomly selected with a probability level that was proportional to their size (Table 6.1).

Table 6.1: Description of farmers' associations or *kebeles* used in the study, sampling framework and sample sizes.

Sampled <i>kebeles</i>	Total No. of households	Sample size
Sombokumi	324	34
Sombowato	511	53
Harolego	290	30
Iero	284	30
Tulunono	512	53
Total	1921	200

Methods of data collection

The research was conducted by analyzing data collected from a structured-type questionnaire, key informant interviews, focused group discussions and non-participant observation. The fieldwork was undertaken in October and March 2014 (total of 60 days). This is because these two months are typically a quieter period when farm activities are relatively less demanding.

Structured questionnaire

In each *kebele*, a list of household heads was numbered from 1 to 'n' and every third household head was selected to distribute questionnaires. This approach was pursued to maintain the randomness of selected households. However, in the absence of the selected household's head for long time from residential area or being unwilling for conducting interview, the first or second in the list would be substituted by random selection. This approach has been satisfactorily used in related studies (e.g., Khatun & Roy, 2012; Okere & Shittu, 2013). The researcher and five trained enumerators directly read the questionnaire to households' heads from which respondents chose one of the given options and determined the feedback from a set of responses given in the questionnaire. Initially, for the smooth operation of data collection, the respondents were informed about the purpose of the survey. For convenience, the questionnaire survey was administered either in early morning or in late afternoon. The questionnaire comprised both close and open-ended questions, which included parameters such as age, sex, educational status, occupation, household size, farm type, land tenure system, farm sizes and trends of fertilizer application as well as types of livelihood diversification.

Key informant interviews

Key informant interviews (KII) were conducted with agricultural development and extension officers and district officials, respectively. The interviewees also included experienced elderly (≥ 65 year-old) household heads. The main reasons for selecting elderly households were that they have holdings for long time, experienced land abandonment and possess different opportunities for livelihood diversification. They were asked their aspiration for diversified livelihood, the reason why people diversify livelihood, the factors and forces that give rise to diversification of livelihoods and some of its consequences on their lives and society. The objective of this part of the interview was to gather an understanding of how the level of diversification has influenced their experience and decision-making of livelihood choice.

Focus group discussions

Six focus group discussions (FGD) for six hours (that is one hour per group) were purposively carried out for the research. One FGD from each of the five *kebeles* (five FGDs in total) consisting of elderly households' heads (two), local government representative (one), extension workers (two) and landless household head (two) were conducted. Seven people participated in each FGD. The sixth FGD comprised experts from the Office of Agricultural and Rural Development, and the Office of Rural Land Use and Administration, respectively. These two district offices were purposely selected because they are the organizations directly responsible for guiding livelihood activities in the area. The number of participants in the FGD was eight in which each office was represented by four. The discourse explored the roles of age, gender, household size, educational level, fertilizer application, land tenure system and landholding sizes on the diversification of livelihood in the study area. In addition, the secondary

data relevant to the study were obtained from local government reports as well as policy, program and project documents from the Ethiopian Ministry of Agriculture and Rural Development.

Definition: Livelihood diversification

Livelihood diversification is defined as a process by which household members make different portfolio of activities in their struggle for survival and in order to improve their standards of living (Ellis, 1998). Accordingly, in this study, livelihood diversification refers to effort made by individuals and households to find alternative and innovative approaches to production, which help reduce risks, increase all dimensions of sustainability, and importantly mitigate impacts on land degradation. Such an outcome should ensure a more resilient livelihood. Diversification can be manifested through cultivating a wider spectrum of crops, rearing different types of livestock, small enterprise, migration or casual labor.

Analytical model

From the range of household characteristics investigated, land tenure regimes, farm practices, mean age, sex, household size, level of education, fertilizer utilization, and size of farming enterprise were some of the determinants of livelihood diversifications (Table 6.2). These variables were also used in related studies (e.g., Ellis, 2000b; Okere & Shittu, 2013). A binary logistic regression model was used to estimate the probability of a binary response based on one or more predictor (independent) variables. The dependent variable, livelihoods diversification, was a binary variable, which took a value of one if a household diversify livelihood and zero if otherwise.

Table 6.2: Household characteristics, variables investigated and description of the analytical model.

Household characteristics	Variable name	Description
Mean age of working household population	age	1= between 15 and 25, 2= between 26 and 45, 3= >45
Sex of household head	gender	1=female, 2=male
Household size	Household size	1= <5, 2= between 5 and 10, 3= >10
Educational level of the household head	education	1= unable to read and write, 2= primary education, 3=secondary school and above
Use of chemical fertilizer at household level	fertilizer	1=increased, 2=decreased, 3=remained the same
Farmland size of the household (ha)	farmland size	1= <1ha, 2= between 1 and 5, 3= >5
Land tenure regimes among the household	tenure	1= sharecropping, 2=extensification, 3= inheritance
Farm type practiced by the household	farm type	1=crop only, 2=livestock only, 3=mixed farming

The cumulative logistic probability model that has been used for this study can be econometrically stated as (Lama, 2014).

$$P_i = F(Z_i) = \frac{1}{1 + e^{-(\alpha + \sum \beta_i X_i)}} \quad (6.1)$$

$$1 + e^{-(\alpha + \sum \beta_i X_i)} \quad (6.2)$$

Where:

P_i is the probability of diversification versus determinants of diversification given as X_i is a vector of explanatory variables, α and β are regression coefficients, which need to be estimated, and e is the base of the natural logarithm.

For ease of interpretation of the coefficients, a logistic model can be written in terms of the odds and log of odd. The odds ratio is the ratio of the probability that a household diversify livelihoods (P_i) to the probability of households that do not show diversification of livelihoods ($1 - P_i$), which is shown below (Lama, 2014).

$$\frac{P_i}{1 - P_i} = e^{z_i} \quad (6.3)$$

Subsequently, by applying the natural logarithm, the equation yields:

$$\text{Ln}\left(\frac{P_i}{1 - P_i}\right) = Z_i = \alpha + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_m X_m \quad (6.4)$$

If the error term, ε_i is taken into account, then the equation becomes:

$$Z_i = \alpha + \sum_i^m \beta_i X_i + \varepsilon_i \quad (6.5)$$

Where the explanatory variables (determinants) used in the model included the following: X_1 is mean age of working household population, X_2 is sex of household head, X_3 is household size, X_4 is education level of the household head, X_5 is use of chemical fertilizer, X_6 is farm size of the household (ha), X_7 is land tenure regimes among the household, X_8 is practiced farm types of the household.

The parameters of the logistic regression model were estimated using the maximum likelihood approach (Baird & Gray, 2014). Frequencies and descriptive statistics have been employed to analyze the questionnaire data collected from household heads using SPSS software version 2.0 (Baird & Gray, 2014).

Results and discussion

Household characteristics

Table 6.3 shows a summary of statistics highlighting the characteristics of the households based on the samples analyzed. Male-headed household dominated the sample (63%) since they are the main decision-makers in the choice of livelihood in rural households. The study also showed that the average age of respondent household heads was 48 year-old; the majority (65%) of which was between 25 and 45 year-old. From this, it is implied that most of the rural household heads are economically active and have a significant contribution towards the overall income collected. It was also found that slightly over half (54%) of household heads had at least undertaken primary education. The households sampled had a large family size, which averaged seven family members. Household size is seen as an important factor because it is the primary source of labor and it influences size of land-holding and land-to-labor unit ratio.

The average farm size within the study area was estimated to be approximately one hectare (standard deviation: 1.11). Therefore, per capita land holding size, that is, land-to-man ratio, was estimated to be 0.14 hectare of land per household. In Ethiopia, land is under the control of the state and community where outright purchase and private ownership of land are legally forbidden (Holden et al., 2011). The functioning and perception of land tenure in the study area is similar to other regions in the country. The households have use-rights that are mediated by customary tenure systems managed at the local level. These systems include inheritance, sharecropping and extensification towards unoccupied lands. The inheritance system represents the main (78%) land tenure regime but it varies depending upon the type of land and age of children. Homestead land is usually given to the youngest child who takes care of the parents, whereas forest and garden lands are divided among other children. Inherited lands are transferred to children when getting married or when they leave the household (Deininger & Jin, 2006).

Both crop cultivation and livestock husbandry represent 90% of the sources of livelihoods of the local people. In the *Meher* (the main cropping season in Ethiopia) season of 2015, cereal production accounted for 85% of the cultivated land. *Teff*, barley and maize were the main cereal crops. In the same year, total livestock population of the area was estimated at 169,333 tropical livestock units.

Table 6.3: Characteristics of households in Northeastern Wollega, Ethiopia ($n=200$).

Household characteristics		Frequency	Percentage
Age of working household heads	25-45	130	65.0
	46-65	60	30.0
	>65	10	5.0
Sex of household head	Female	75	37.5
	Male	125	62.5
Household size	1-5	84	42.0
	6-10	79	39.5
	>10	37	18.5
Education level of the household head	Illiterate	47	23.5
	Primary education	108	54.0
	Secondary education and above	45	22.5
Use of chemical fertilizers	Increased	175	87.5
	Decreased	19	9.5
	Remained the same	6	3.0
Farmland size (ha)	<1	47	23.5
	1.1-5	146	73.0
	>5	7	3.5
Land tenure regimes	Share cropping	39	19.5
	Extensification	5	2.5
	Inheritance	156	78.0
Farm type	Crop cultivation	7	3.5
	Livestock rearing	3	1.5
	Mixed farming	184	92.0

Results from the focus discussion groups conducted with experts and household heads revealed that the old tradition of breeding large number of livestock is still a common system in the study area. This is due to the high social value of owning large number of livestock. Moreover, livestock provides an important source of animal power for cultivation of the soil and threshing. Horses, mules and donkeys are also essential as a means of transport for both people

and agricultural products. To some extent, livestock confers a degree of food security in the event of crop failure. Manures derived from livestock also provide an important source of nutrients for crop production and maintenance of soil fertility, which is highlighted in several studies (e.g., Codjoe & Bilsborrow, 2011; Adepoju & Olaniyi, 2014).

Both mono cropping and crop rotations are practiced in the study area. In the homesteads, potato, spices and cabbages are often intercropped with maize. The study showed that the crop sequence used in the rotation is influenced by the preferences of households. However, as confirmed by elders, the sequence *teff*→*neug*/leguminous→maize/barley→*teff* is the most common system. This approach is mainly aimed at securing food requirements for the family and maintaining soil fertility. In this system, *neug* (*Guizotia abyssinica* L.) is always cropped after *teff*, while the sequence of other crops is more flexible. This is because the rhizobium bacteria that occur in roots nodules of *neug* fix atmospheric nitrogen, which is used by the plant (Pretty et al., 2011). The decomposition of *neug* stalks in the field unlocks nitrogen into the soil and enhances soil fertility. In addition to *teff*, wheat, barley and *neug* offer similar protection against erosion. The use of intercropping offers advantages over mono-cropping practices as it contributes to minimize risks and therefore stabilizes farm income, maintains soil health and makes more efficient use of labor (Osabuomen & Okoedo-Okojie, 2011).

The traditional oxen-drawn plow used to be the main tool for cultivating the soil however repeated operations are subsequently required to produce a relatively fine seedbed (Lal, Reicosky & Hanson, 2007). The purpose of repetitive plowing is to control weeds and provide a suitable seedbed to establish the crop (Kayombo & Lal, 1993). In the absence of appropriate protective measures, overworking of the soil can increase the susceptibility to erosion and runoff, particularly during the first period of the rainy season (Asmamaw et al., 2011). For example, the

preparation of fields for establishment of *teff* involves plowing up to six or seven times whereas for *neug*, barley and maize, the soil is plowed three or four times. The fields are commonly covered with a single crop established down-slope when the final plowing is performed to facilitate surface water drainage, which can encourage erosion processes. Though all of the interviewed households were in favor of application of chemical fertilizers, many of them apply fertilizers well below the amounts recommended by development or extension agencies (typically, 100 kg ha⁻¹ combination of all nutrients into one blended fertilizer). This finding is in close agreement with a study conducted by Kraaijvanger & Veldkamp (2015), which suggest that under-fertilization may be a factor that limits productivity and does not allow for balanced nutrient cycles at the field-scale. Despite this, Tanner et al. (1993) emphasized that increased use of fertilizers must be accompanied by the provision of crop protection measures to enable for increased productivity. Almost 90% of the household heads indicated that the amount of chemical fertilizer used in their farms, such as urea and di-ammonium phosphate, increased by approximately 65% between 2009 and 2014. At the regional-scale, this means that fertilizer consumption increased from 3900 to 5800 tons per year in the same period. Despite this, the actual amounts used on farms remains below levels suggested by development agents, which suggests that yield potentials are not being realized.

The combined use of modern crop varieties, now available to most farmers, with improved agronomic management practices, particularly for crop protection, and higher fertilizer inputs has potential to narrow yield gaps and advance food security in this region. However, a common belief amongst the farmers interviewed is that the use of new varieties and improved crop protection practices are sufficient to increase crop yields with relatively less importance on improved crop nutrition. Given the total number of household is 1921, per capita di-ammonium

phosphate and urea fertilizers consumption increased from 200 kg to 300 kg per household in the same period. This mean a household is currently applying in average 300 kg of a combination of blended fertilizers to the completely cultivated land. Additionally, compost prepared from locally available materials like leaf of plants, crop residues and animal dung is used on farms. This is because farmers recognize that composts have significant benefits in terms of soil productivity, maintenance of soil quality and reduced cost of chemical fertilizers.

Typology of livelihood diversification

Diversification is regarded as an important livelihood strategy in the area. Slightly over half (55%) of the households have some kind of diversified activities. In most households, at least one family member was temporarily or permanently working on off-farm or non-farm activities. Land-poor farmers employed by wealthier neighborhood farmers in the form manual labor to increase their family income and enhance households' livelihood persistency. The percentage of households in favor of diversification varied from 37% (rated diversification as important) to 51% (rated livelihood diversification as very important). Rural households developed different kinds of livelihood strategies, grouped into the following nine clusters: (1) trade: livestock, coffee, food, cloth, soap, kerosene and honey; (2) unskilled daily wage labour: food for work, agriculture labour, painting, pottery and sand collection; (3) cultivator: land preparation, ploughing, irrigation, sowing/planting, weeding, application of fertilizers and pesticides, harvesting, threshing, transporting and storing; (4) herder: feeding/treating, milking and marketing; (5) artisanship: blacksmith and tanner; (6) government employee: health worker, manager of *kebele* council, maid and guard; (7) handicrafts: carpenter, spinning, roof thatching and mat making; (8) forest products: charcoal, wood, grass and lumber making; (9) service provision: shoe shining, barber, grain mills, traditional medicine, tailor, preacher, rain maker and

fortune teller. This agrees closely with studies undertaken across sub-Saharan African countries that showed diversification is a response to agricultural risks, land degradation in particular and opportunities for developing new markets (Tittonell et al., 2010; Bowser & Nelson, 2012; Zewdu et al., 2014; Kebebe, Duncan, Klerkx, de Boer & Oosting, 2015).

Table 6.4: Response to reasons for households’ diversification of livelihood opportunities in Northeastern Wollega, Ethiopia

Reasons for diversification of livelihood	Response (%)
Response to land shortages	62
Advices from development agents	25
To accumulate capitals	8
Technology, skills and knowledge advancement	5
Total	100

Table 6.4 presents common reasons for livelihood diversification in the study area. Households diversify their livelihood mainly in response to land and input shortage (63%), and advise from development agents to change traditional farming systems or production orientations (25%). The former reason is a “push-factor” whereas the latter is a “pull-factor”. The “push-factor” is motivated by risk aversion in the presence of land constraints derived by population pressure and fragmented land holding. Professionals and colleagues can technically support households. Experts’ advice encourages adoption of agricultural technology packages and productivity improvement in the presence of land degradation. This implies that while professionals become a means for technology acceptance and complemented scientific research, copying of colleagues is essential for technology adoption. This suggests that diversification of livelihood activities are triggered by opportunities and constraints confined by local or individuals’ circumstances.

Determinants of livelihood diversification opportunities

The pseudo-R² of the maximum likelihood estimate of the logit model was found to be 0.68 (Table 6.5). This implies that 68% of the likelihood of livelihood diversification activities is explained by the independent variables. The marginal effects of independent variables were estimated to consider their roles in the decision making of households' diversification activities. Four of the eight variables considered in the model and explained hereunder, such as household size, farm size, tenure system and gender were found to have significant impact on livelihood diversification (Table 6.5).

Table 6.5: Parameter estimates of the determinants of livelihood diversification in Northeastern Wollega, Ethiopia

Variables	Coefficients	S.E	Wald	Odds ratio	P-values
Household size (< 5 families)	5.36	1.63	10.78	0.001	0.005
Household size (5 -10 families)	4.72	1.68	7.91	0.005	0.009
Farm size (<1 hectare)	4.21	1.59	6.98	0.008	0.015
Farm size (1-5 hectares)	24.33	1.27	0.000	0.998	0.000
Tenure regime (sharecropping)	0.07	2.96	0.000	0.982	0.067
Tenure regime (extensification)	-2.44	1.36	3.23	0.072	0.087
Female headed household	-6.79	1.39	23.99	0.011	0.001
Constant	12.58	3.34	14.20	0.000	0.001
Pseudo R ²	0.68				
Log Likelihood function	35.9				
Observations	200				

Household size

Household size had a positive and significant correlation with livelihood diversification at 5 and 10% level of significance for households who had 1-5 and 6-10 family size, respectively. It is therefore more likely for diversification to evolve among the household having

a larger family size. Family size affects the ability of a household to supply labor to the farm, as discussed earlier. The diversity of livelihood strategies varies from household to household depending on family size and their skills. A household having larger size may seek other income-generating activities for sustainable livelihood than a smaller size. This scenario is consistent with the results of studies conducted by Geda, Shimeles & Weeks (2009) in Ethiopia as well as Mcdonagh, Lu & Semalulu (2014) in the Eastern Ugandan Hills. Household size, which constitutes children and hired laborers, increases households' capability to diversify livelihood by supplying labour to the farm. In a large family, some members may continue farming in a traditional system while others may choose to work on non-related farming activities. The implication of this is that household size could decrease the danger of livelihood collapse among the farming community.

Households allocate at least part of their labor to the nonfarm sector because of better returns from nonfarm sector or inadequate farm outputs (Figure 6.1). This decision is important to manage agriculture risk, compensate for land constraints, take advantage of profitable opportunities of off-farm, and cope with harvest shortfalls in the absence of the crop insurance or consumption credit market. Hence, household allocation can either be long-term or short-term strategies to diversify livelihood. Examples of recent empirical studies showing these household strategies include Tiftonell et al. (2010) in Kenya and Uganda, Kebede et al. (2015) in Ethiopia, and Cornish et al. (2015) in the Eastern Indian Plateau.

Farmland size

Farmland size had a significant and positive influence on opportunities of livelihood diversification. Households with larger farm sizes tended to have a more diversified livelihood compared with smaller holders. This was expected since farmland is the most important source

of livelihood in the study area. Hence, larger farm size implies that wealthier households would tend to have higher levels of income available for diversification. Based on Browser and Nelson (2012), this study argues that landless and smallholder farmers encounter difficulties in the process of diversifying livelihood opportunities. This suggests the existence of access barriers into diversified livelihood for households who lack the land asset. With an expanding population, there will be more pressure on land to be used for other purposes such as urbanization, conservation areas and grazing lands among other uses. This also means that there is a pressing need for available agricultural land to remain productive. These pressures are also mentioned in several studies (e.g., Geda et al., 2009; Amare & Belaineh, 2013; Mcdonagh et al., 2014).



Figure 6.1: Evidences of rural livelihood diversification in Northeastern Wollega, Ethiopia

Land tenure regimes

Sharecropping had a significant and positive effect on determining livelihood diversification. This indicates that households that depend on sharecropping are more likely to diversify their livelihood. The possible explanation for this is that the output from sharecropping would be insufficient to maintain the livelihood of a given family. As a result, there need be other sources of income and activities to fulfill as a means of subsistence. By contrast, extensification was found to be significant but it was also a negative determinant of

diversification. Land is owned by state whereas private land ownership is outlawed. This implies that access to land needs to be viewed through the same lens of widening options and opportunity as livelihood diversification itself (Lanckriet et al., 2014). This also agrees with Zewdu et al. (2014) who stated that land tenure regimes, which imply ownership security, could affect the level of diversification activities. Kuman & Quisumbing (2012) further demonstrate that tenure regimes control household quit or enter farming and rental transactions in farmland. Thus, households having insecure tenure regimes are vulnerable to food insecurity (Quin et al. 2012). This is because it could be difficult to produce food, to accumulate asset and to cope with land degradation and other environmental stresses without secured ownership of farmland.

Sex of household head

Female-headed household was negatively related with the level of livelihood diversification. A possible explanation could be that females rent land to male-headed households because they lack the tools required to cultivate the land (e.g., oxen plows, seeds). As demonstrated through key informant interview, renting of land provides the use-right of the land from the holders to the renters for three years with possibility of renewal. This result is consistent with the findings of Amare & Belaineh (2013) who argue that sex of household heads affects the type of livelihood diversification activities. The choice of income-generating occupations (both farm and non-farm) is attributed to culturally defined roles, social mobility limitations and ownership of assets differentiated between men and women. Restrictions of women's access to formal education, productive assets and credit are other reasons of gender-based differentiation of diversification activities. This, in turn, determines that individuals play different roles and activities within households and have therefore varying degrees of autonomy and control over resources. Our

study encourages women to undertake a leading role in both agriculture and non-agriculture livelihoods.

Conclusions

This study was designed to identify determinants of livelihood diversification among rural households of Northeastern Wollega, Ethiopia. Data derived from 200 household heads were analyzed using a combination of descriptive and analytical tools. The main outcomes of this research are summarized in the following paragraphs:

- Young age groups, large family size, small per capita land holding and at least primary education characterized the households investigated. Inheritance of family land is the major tenure system in the area. Farming, including cultivation of food crops and livestock husbandry, is the primary occupation within the study region, and complements well with diversified livelihood such as artisanship, trading, salary jobs (off-farm) and asset income. This suggested that the study area is undergoing a major transition in livelihood to reduce vulnerability. Multiple reasons prompt households to diversify livelihoods, which are a combination of pull and push factors,
- The results of the logit regression model showed that four out of eight postulated independent variables were significant. These were household size, farm size, tenure system and gender of the farm households. The impact of household size and farm size on livelihood diversification are positive implying that there is high likelihood of diversification among households that have larger family size and extensive farmland. The impact of tenure system can be positive or negative depending upon the type of system adopted at the farm. For example, sharecropping was positively associated with diversification while extensification of cropland had a negative relationship with rural

livelihood diversification. Diversification is likely to be less common among female-headed households.

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Chapter 7

Summary and conclusion

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It is generally believed that land degradation is the major environmental constraint impending sustainability of agricultural growth in Ethiopia. The highlands are the most affected area because of the heavy pressure from human and livestock populations. Simultaneously, there is strong commitment from a variety of stakeholders to reverse the scenario and rehabilitate degraded land. However, the country has not yet overcome the problems land degradation such as declining properties of soil and land productivity, in turn food insecurity and rural poverty. Land degradation is a threat to smallholders in Northeastern Wollega. The main challenge for agriculture is to reverse the ongoing problems of land degradation. This led to the present study making detailed explorations into the drivers and impacts of land degradation and adaptive mechanisms at local level. This research was addressed by analyzing the land-use/land cover dynamics over a period of 43 years.

Satellite images, focus group discussion and key informant interview have used to investigate drivers of land-use/land cover dynamics and the consequences of these dynamisms on environment and local livelihood. The spatial variations of soil physical and chemical properties were measured. The purpose of this measurement was to assess the spatial variations of soil properties under different land-use/land cover types, forestland as control. For this purpose, soil samples have collected from natural forest, shrubland, grassland and cropland. The soil in forestland is considered as a reference to assess how large is the change in soil properties under other land-use/land covers. In addition, the effects of soil depth on the variability of soil properties have studied under the respective land-use/land covers. One way ANOVA and correlation coefficients have used to test mean differences of the soil properties and identify the associations between different soil properties, respectively.

Moreover, land-cover transitions were analysed using a transition matrix obtained from cross-tabulation of the two-raster maps. The general structure of the transition matrix has demonstrated to identify swap, vulnerability of land-cover types to transitions and major signals of systematic changes. Livelihood diversification is considered as the main adaptive strategy with the negative impacts of land-use/land-cover change. Cross-sectional survey of 200 households are randomly selected by two-stage sampling, which are designed to collect data relating to households' socio-economic characteristics, income-generating activities and determinants of agricultural diversification. These data were collected using structured questionnaires, key informant interviews and group discussion and analyzed using descriptive statistics and logit regression model. Thus, the major findings from this study are briefly presented here.

Analysis of satellite imagery indicated that land-use/land-covers have been substantially changed during the 43 years period considered. The major changes are expansion of cultivated land and settlement, and a sharp decline of forest, grass and shrub lands. Since 2005, however, the areal extent of cropland and shrubland has decreased and increased, respectively. Cropland experienced the highest (19%) loss, while shrubland experienced the highest gain (22%), gain-to-loss ratio (63), gain-to-persistent ratio (47) and positive net change-to-persistent ratio. Grassland was the most stable land-cover type. The transition process is dominated by systematic processes of change and with very few random processes of change. This can be interpreted as land-cover transitions are due to regular or common processes of change. The drivers of LULCC include rapid population growth, poor farming system, rising number of livestock population, insecure land tenure systems, limited access to agricultural inputs and credit. The major impacts of land-use/land-cover changes were manifested as destruction of natural habitats and disruptions of

ecosystems' functions, water shortage, rainfall variability, declining land quality and agricultural productivity.

Land-use/land cover changes are responsible for the deterioration of physical, chemical and biological soil parameters. The cultivated land has lesser organic matter, total N, cation exchange capacity and exchangeable basic cations (Ca^{2+} and Mg^{2+}). The deterioration of soil parameters are attributed to accelerated rate of erosion and deposition on the agricultural land. Traditional farming system and poor land management practices (i.e., poorly designed terracing and cut-off drainage) are the major constraints impending soil removal. Conversely, available P, clay content, soil acidity and exchangeable K^+ were highest on the cultivated land. These have been caused by the process of plowing, clearing, disposing and leveling of farming fields and application of inorganic P-fertilizers on the cultivated land. Tillage is very intense and soil is left bare for at least five months.

Most of soil parameters such as sand, organic matter, total N, available P and exchangeable cations (Ca^{2+} , Mg^{2+} and K^+) decreased as soil depth increased on the selected land uses (forestland, grassland, shrubland and cultivated land). Except available P, all have experienced highest decline on the forestland due to abundance of plant litter and biomass production on the topsoil of forestland. Under forestland, there are active biological activity and better interception and infiltration that accelerate the rapid decline of soil properties with increasing soil depth. On the other hand, on the cultivated land annual crops remove available P after harvest. These are likely to reduce crop yield and productivity of land and in turn, livelihoods of the local community. Few soil parameters like cation exchange capacity are increased as soil depth increased for the forestland and cultivated land. Thus, the variability of soil properties is attributed land-use/land cover changes and soil depth at local scales.

Households diversify livelihood to adapt with adverse impacts of land-use/land-cover changes and deteriorating soil properties. Most of the rural household heads in the study area are economically active and have significant contribution to the growth of agricultural production. The average age of household heads was 48 years and dominated by male-headed household. Slightly over half of the household heads had at least primary education. The households had a large family size, which is the primary source of labor. Household size also influences size of land-holding and land-to-labor unit ratio. Per capita land holding size is estimated to be 0.14 hectare of land per household. The customary tenure systems include inheritance, sharecropping and extensification towards unoccupied lands. The sources of livelihoods of the local people are both crop cultivation and livestock husbandry. 85% of the cultivated land covered with cereal production. Mono cropping and crop rotations are the main cropping systems, which are aimed at securing food requirements for the family and maintaining soil fertility.

At least one family members of a household is temporarily or permanently engaged in off-farm/non-farm activities. The most important activities include trade, unskilled daily wage labour, cultivator, herder, artisanship, government employee, handicrafts, forest products and service production. From the range of household characteristics investigated, household size, farm size, tenure system and gender are found to have significant impact on livelihood diversification. Household having a larger family size and farm size and those who are dependent on sharecropping are more likely to diversify their livelihood.

In conclusion, empirical studies conducted in the northeastern Wollega revealed that human-environment relationship is complex. The main forms of land degradation are deforestation, abandonment of cultivated land, adverse changes in soil properties and deletion of biodiversity. These suggest the importance of holistic adaptive strategies, and great effort and

resources to ameliorate degraded lands. This could be a key strategy towards achieving a sustainable agriculture that enables the inhabitants to produce for food sufficiency and market supply. The recent efforts at land and soil conservation practices did bring positive consequences by greening landscapes and diversifying livelihood of local communities. However, sustainable solution to the problems of land degradation and enhance access to lucrative livelihood should include (1) easing population pressure on land by modifying the national population policy adopted in 1993; (2) reduce the livestock pressure on land by introducing modern livestock husbandry and pasture administration practice (e.g., introducing improved breeds and promoting controlled grazing); (3) assist farmers with services like credit and market provisions, electricity, education, health posts, and building rural roads, which will, in turn, contribute positively towards livelihood diversification and land conservation; (4) adopt policy interventions, which may guarantee property right in productive assets such as land, livestock and labor availability.