ASSESSMENT OF ENVIRONMENTAL-LIVESTOCK INTERACTIONS IN CROP-LIVESTOCK SYSTEMS OF CENTRAL ETHIOPIAN HIGHLANDS

By

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DECLARATION OF ORIGINALITY

I declare that the work presented in this Thesis is original, to the best of my knowledge and belief, except as acknowledged in the text and that the material has not been submitted, either in whole or in part, for a degree at this or other universities. I also declare that I have complied with the rules, requirements, procedures and policy of the university.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS

AOAC	Association of Official Agricultural Chemists
ASA	American Society of Agronomy
C	Carbon
Ca	Calcium
CCCM	Canadian Climate Center Model
CCREM	Canadian Council of Resource and Environment Ministry
Cd	Cadmium
CDIAC	Carbon Dioxide Information Analysis Center
CEC	Cation exchanging capacity
CGM2	Canadian Global Climate Model 2
Co	Cobalt
Cr	Chromium
CSA	Central Statistical Authority of Ethiopia
Cu	Copper
DIVA GIS	Diversity Analysis Geographic Information System
DM	Dry Matter
EDRI	Ethiopian Development Research Institute
EPA	U.S. Environmental Protection Agency
ESAP	Ethiopian Society of Animal Production
FAO	United Nations Food and Agricultural Organization
FAOSTAT	FAO-online annual Statistics
FDA	U.S. Food and Drug Administration
Fe	Iron
FEWS Net	Famine Early Warning System Network
GCMs	General Circulation Models
GFDL	Geophysical Fluid Dynamics Laboratory model
GIRDC	Generations Integrated Rural Development Consultants
g	Gram
GTP	Growth and Transformation Program, Ethiopia
HaDCM3	Hadley Center Coupled Model, Version 3

Hg	Mercury
IFPRI	International Food Policy Research Institute
ILCA	International Livestock Centre for Africa
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel for Climate Change
IPMS	Improving Productivity and Market Success for Ethiopian Farmers
IUCN	International Union for the Conservation of Nature
IWMI	International Water Management Institute
K	Potassium
m	Metre
Mn	Manganese
Mo	Molybdenum
MOA	Federal Democratic Republic of Ethiopia Ministry of Agriculture
MoFED	Federal Democratic Republic of Ethiopia, Ministry of Finance and Economic Development
MoWR	Federal Democratic Republic of Ethiopia, Ministry of Water Resources
N	Nitrogen
Na	Sodium
NAPA	National Adaptation Program of Action, Ethiopia
NAS	US, National Academy of Science
Ni	Nickel
NMSA	National Meteorological Service Agency, Ethiopia
NRC	US, National Research Council
^{o}C	Degree Celsius or degree centigrade
OCHA	U.N., Office of Coordination Humanitarian Affairs
OM	Organic Matter
P	Phosphorous
Pb	Lead
PCM	Parallel Climate Model
Se	Selenium
SOC	Soil Organic Carbon

SPSS	Statistical Package for Social Sciences
SRES	Special Report on Emission Scenarios
TLU	Tropical Livestock Unit
UKMO-89	United Kingdom Meteorological Office, 1989 model
UNESCO	United Nations Scientific and Cultural Organization
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States Dollar
WFP	World Food Programme
WHO	World Health Organization
WOCAT	World Overview of Conservation Approaches and Technology Categorization System
WRI	World Resources Institute
Zn	Zinc

Assessment of environmental-livestock interactions in crop-livestock systems of central Ethiopian highlands

By

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ABSTRACT

The study was done in Adaa district which is one of the 12 districts in East Shoa zone in Oromia regional state of Ethiopia. It is located southeast of Addis Ababa at 38^{o}51' 43.63'' to 39^{o}04' 58.59'' E and 8^{o}46' 16.20'' to 8^{o}59' 16.38'' N, on the western margin of the Great East African Rift Valley. The altitude ranges from 1 500 to ≥ 2 000 meters above sea level. The district has a high potential for mixed livestock and crop production systems. The purpose of this study was to make up for the paucity of information on livestock and environment interaction by assessing the relationship of livestock, soil, water, land, climate and crops under mixed crop-livestock production systems in central Ethiopian highlands.

The objectives of the study were: (a) to assess the effect of change in land management on carbon storage and the contribution of livestock to carbon storage; (b) to examine the impact of livestock on natural resources and the environment; (c) to assess the effects of the change in traditional agricultural practices, expansion of factories, slaughter houses, greenhouses and flower farms on water and soil quality; (d) to evaluate the effect of climate change on livestock production under small-scale agriculture; and (e) to recommend options for mitigation and adaptation to environmental changes.

The research design was non-experimental and did not involve the manipulation of the situation, circumstances or experiences of the interviewees. The design was comparative research that compared two or more groups on one or more variables, such as the effect of agricultural land use management, tillage type etc. on carbon storage in the soil. This research also applied a longitudinal design that examined variables such as the performance exhibited by groups over time. Purposive sampling was often used to measure the effect of agricultural, industrial effluent and human interferences on the environment by measuring nutrient contents at sources in the soil, water and manure. Biological data were complemented by key socio-economic survey by interviewing individual farmers and focus groups from sampling sites. Secondary data were also reviewed to measure soil degradation and run-off attributed to livestock.

Results showed that animal waste and farmyard manure had the highest contribution in the addition of carbon in the soil. This implied that for most of carbon inputs livestock products and by-products had a greater place in the carbon sink. Therefore, livestock production could be considered as one of the major agricultural production systems in soil carbon storage. Similarly, livestock production systems also play an important role in maintaining the eco-system balance through nutrient recycling.

On the average, the number of livestock per household for most species increased during the Derge regime in the 1990s compared to the Haile Sellassie regime in the 1970s when people did not own land; and then the number declined in the 2000s except for equines, crossbreeds and oxen. The change to crop intensification led to the change in the purpose for livestock keeping. Farmers started keeping certain types of animals for specific purposes unlike before when livestock was kept for prestige and economic security. The major drive for the change of attitude towards the purpose of keeping livestock was scarcity of resources, mainly feed and water. Equine ownership has significantly increased due to their low off-take rate and their feeding habits which allowed them to survive in harsh environments where feed resources were extremely scarce.

There was a significant difference in crop response to manure application. Vegetables produced higher yields with manure than chemical fertilizers. Cereals on the other hand responded more to chemical fertilizers than to manure. Therefore, combining manure and chemical fertilizers was the best option for the sustainability of crop production in the study area. Some of the limitations to the use of manure as an organic fertilizer were inadequate manure production, high labour cost, bulkiness and high cost of transport to the fields and weed infestation. Manure management systems in the study area were affected by livestock husbandry practices. Only crossbred cattle (5%) were zero-grazed and used; and manure was stored in pits as slurry. Indigenous cattle were grazed outdoors in the fields during the day and at night they were kept in kraals near homesteads. There was a substantial loss of nutrients during the day when animals were grazing in the fields through leaching and trampling of dung and urine patches. Indoor or zero grazing of livestock could reduce nutrient losses.

The use of manure as fuel in the study area had no significant effect on CO_2 emissions at household or local level, but had a negative impact on soil organic carbon storage and soil fertility. Therefore, for improved yield and balanced eco-systems manure burning has to be replaced by other alternative energy sources such as bio-gas and kerosene. The largest carbon equivalent emissions were from CH_4 (72.6%), N_2O (24%) and CO_2 (3.4%) which indicated the need to improve livestock and manure management systems under smallholder agriculture.

Overall, there was an indication of a decline in water resources on per capita basis. The major contributing factors were combined pressure of human and animal population on natural resources that led to excessive deforestation, loss of biological diversity, overgrazing, soil degradation and various forms of pollution and contamination. The global climate change also played a role in the decline in water resources due to the decrease in annual precipitation and increasing temperatures. Urbanization and economic growth increased the demand for milk and meat, which required additional water use for each unit of increased animal protein. The demand for milk and meat is expected to double in the next 20 years with an annual growth rate of between 2.5 to 4%.

From the sixty-year meteorological data (1951-2009) there was an established increase in rainfall by 2% per annum; and maximum and minimum temperature by 0.08^{o}C per decade, which amounted to a cumulative temperature increase of 0.5^{o}C in the last decade. The increase in precipitation and temperature favoured the adaption of lowland crops like maize and sorghum to highland agro-ecology. Climate prediction models forecasted that most of the highlands in Ethiopia will remain suitable for cereals like wheat and Teff for the next 50 to100 years. However, the perception of farmers indicated that they felt more heat and warm weather than they have experienced before. They reported that rainfall is now more erratic or comes late and stops earlier before plants completed their vegetative growth.

Key words: Environmental interactions, heavy metals, industrial effluent, farm yard manure, soil organic content, climate change

CHAPTER 1: INTRODUCTION

1.1 Background

Environmental problems are becoming global issues because of their effects on all nations of the world. These are present day major interests of political, economic, social and environmental concerns because of their potential negative impacts to our lives and the ecosystem in general (IPCC, 2007). Climate change is characterized by increased frequency and intensity of extreme weather patterns including storms, floods, droughts and irregular rain over time (FAO, 2006).

The universal atmosphere plays a key role in the exchange of radiant energy between the earth and the sun. The greenhouse effect or the heat trapping property of the atmosphere keeps the annual average surface air temperature of the earth at about +ve15ºC. Without this natural phenomenon the earth's annual average temperature would be -ve18ºC and life would not exist at such a low temperature (NMSA, 2001). This important function of the atmosphere is being threatened by the rapidly increasing concentration of greenhouse gases (GHGs) in the atmosphere as a result of anthropogenic factors. Currently, about 7 billion tons of carbon is released annually into the atmosphere from the burning of fossil fuels and deforestation (FAO, 2011). By 2050 the average annual global surface air temperature is predicted to increase by between 1.1ºC to 6.4ºC and the sea level will rise by between 18 cm and 59 cm (IPCC, 2007). These predicted increases have been partially attributed to the accumulation of GHGs in the atmosphere.

Such drastic change of climate and sea level in a short span of time is expected to have adverse impacts on many socio-economic sectors. The most vulnerable are low-lying areas and coastal wetlands, agricultural production, water supplies, human health and terrestrial and aquatic ecosystems. It is also expected that changes in the earth's climate will hit developing countries like Ethiopia first and hardest because their economies are strongly dependent on crude forms of natural resources and their economic structures are less flexible to cope with such drastic changes (Stern, 2007)

In the case of quantitative economic losses due to climate change, an estimated €15 billion loss was reported in the United Kingdom and France. An estimated 300 000 deaths in Asia due to flooding and other natural calamities were recorded (Anderson and Bausch, 2006). Although there is some controversy on the reality of climate change, a lot of natural disasters in the form of floods, storms including hurricanes, extreme heat and drought have already been experienced in some parts of the globe (Yesuf *et al.,* 2008).

The 1984-85 famine in Ethiopia caused an estimated one million deaths and made millions more destitute (NMSA, 2001). The crisis was located in the northern highlands of the country where record low rainfall was reported. Again in 2009/10 Ethiopia suffered another serious food crisis after 25 years after the previous famine in the 1980s (MoFED, 2011). The second time, more than 6 million people needed emergency food aid on top of the 7.5 million who were receiving government aid in return for work on community projects as part of the National Productive Safety Net Program. Across the region, about 23 million people were badly affected during the second cycle of the wide spread drought. Then why is Ethiopia still food insecure even after 25 years since the first famine in 1984? The reason is that in addition to global climate change, Ethiopia's population has doubled in the past quarter of a century to 80 million, thus putting greater strain on natural resources (MoFED, 2008). The infrastructure is still poor and the means of agricultural production and marketing remain the same. The country suffered severe drought every 10-15 years during the last century. By 1984 there were droughts every ± 8 years but recently there have been droughts every ≤ 2 years; in 2006, 2008, 2009 and 2011. Climatologists predicted that by 2034, i.e. 50 years after the 1984 Ethiopia famine, what are now droughts will become the norm, hitting the region three years out of every four (Yesuf *et al*., 2008).

The situation in 2011 worsened when weather conditions over the Pacific, including an unusually strong La Niña, interrupted seasonal rains for two consecutive seasons in the horn of Africa (OCHA, 2011). The rains failed in Somalia for two consecutive years (2009 and 2010) and in 2011 in Kenya and Ethiopia. In many areas, the precipitation rate during the primary rain season from April to June was less than 30% of the average rainfall for 1995 - 2010 (OCHA, 2011). The lack of rain led to crop failure and widespread loss of livestock, as high as 40–60% in some areas, which decreased milk production. As a result, the price of cereal grains rose to record high levels while livestock prices and wages fell, reducing purchasing power across the region. Therefore, if the global temperature in East Africa should rise to within the predicted scale, it could result in more crop damage, malnutrition, outbreak of diseases, land degradation and damage to infrastructure (Stern, 2007).

The agricultural sector in Ethiopia contributes 50% to the Gross Domestic Product (GDP) and is a way of life for 85% of the population (2011). It is also the earner of 90% of foreign exchange through exports of raw materials and agricultural products. Despite its contribution to the economy, this sector is affected by climate related disasters such as floods, drought and extended dry spells. Climate change reduced the growth rate of the contribution of agriculture to the GDP from 18% in 1986/87 to 0% during 1991/92 drought year. The fluctuation in real GDP growth rate was mainly attributed to weather variability, which affected agriculture directly (NMSA, 2001).

The major land uses in Ethiopia are livestock grazing and browsing, crop production and nature conservation in forests and woodlands. According to NMSA (2001) more than 50% of Ethiopia's land is used for livestock grazing and browsing. Grazing and browsing occurs mainly in open grasslands, around cultivated areas, shrub lands, road sides and wetlands. Crop production forms the second largest (± 23%) land use while forests and woodlands cover about 7% of the country. Bare lands constitute 16% in the form of exposed rock, salt flats and sand dunes.

According to FAOSTAT (2012) the population of livestock in Ethiopia in 2010 was estimated at 50.9 million cattle, 26 million sheep, 22 million goats, 8.1 million equines and 808 thousand camels; that is a total of 108 million heads, which is ranked the largest in Africa and the 10th in the world. About 95% of the livestock population is kept by subsistence farmers. It forms a large component of the Ethiopian agricultural sector and is well integrated with the crop production systems in the highlands and provides the sole means of subsistence for the nomadic pastoralists in the lowlands. It is the source of many social and economic values such as food, draught power, fuel, cash income, security and investment in both the highlands and the lowlands/pastoral systems (Hadera, 2001). Livestock production accounts for 27% of total agricultural GDP.

Livestock resource is characterized by low productivity. Average carcass yield per animal slaughtered or milked is estimated at 110 kg of beef, 10 kg of mutton or 213 kg of milk per annum (NMSA, 2001). Livestock production growth rate is very small compared to human population growth rate, and as a result there is a decline in per capita consumption of livestock products. Currently, the per capita consumption of milk and meat is estimated at 18.9 kg and 8.3 kg per annum, respectively **(Figure 1.1)**. However, due to current economic reforms the economic growth and per capita consumption of milk and egg had an upward surge in 2010.

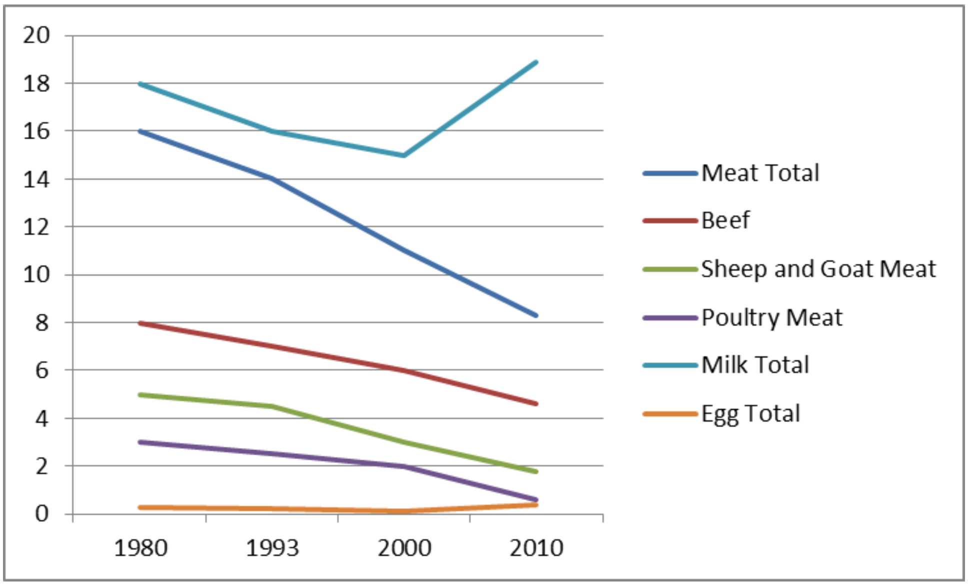

Figure1.1: Trends in annual per capita consumption of livestock products
Source: FAOSTAT (2012)

In recent decades global economy has shown some economic expansion. Amongst the factors that contributed to economic growth are population growth, technological advancement, socio-economic and political changes including trade liberalization. In developing countries, this growth has translated into rising per capita incomes, and an emerging middle class with a different taste and purchasing power. Ethiopia is one of the fast growing countries in sub-Saharan Africa (World Bank, 2011).

From 2001 to 2010, the per capita GDP grew by more than 2% a year for many developing countries (World Bank, 2011). Ethiopia grew by 8% on average during the last decade (World Bank, 2011). Delgado *et al.* (1999) reported that there is a positive correlation between income growth and increasing demand for livestock products. The growing demand for livestock products due to economic and population growth will require the improvement of the existing livestock productivity.

Livestock is a key development sector because it involves the livelihoods of the poor as much as it is the source of animal protein for the emerging middle class who consume increasing amounts of meat, milk and eggs. Thus livestock serves the interest of both the poor and the middle class (FAO, 2006). However, the livestock sector has also been identified as one of the top two or three most significant contributors of the most serious environmental problems from local to global scale (FAO, 2006).The sector has gradually evolved to become an environmental threat to the survival of ecosystems. The danger of to the environment varies according to whether the country is developed and developing as wells as to the type of production systems.

In developed countries livestock industry has had a shift in geographic area in the type of species due to intensification and industrialization (FAO, 2006). Livestock production has changed its area from rural to urban and peri-urban, to get closer to consumers, or nearer to inputs such as feedstuffs, transport and trade routes. There is also a shift in species focusing more on monogastric animals for their fast growth, quick returns for investment, less space required and high efficiency. Consequently, nutrient upload, waste disposal and greenhouse gas emissions are critical environmental problems in developed countries.

In developing countries livestock industry is predominantly in the care of small-scale stock keepers and pastoralists. The critical environmental problems are land degradation due to overgrazing, compaction and trampling, negative impact on water resources through erosion, sedimentation and pollution, enhanced loss of biodiversity due to deforestation, as well as facilitation of invasion by alien plant species (FAO, 2006). The diversity of production systems and interactions makes the analysis of livestock-environment interfaces complex and sometimes controversial (FAO, 2006). The sector relies on multiple natural resources (land, water and vegetation) which are scarce and are equally important for the development of other sectors. Both intensive and extensive livestock production systems require careful management to reduce negative impacts and enhance positive impacts on natural resource bases locally and globally (Lemus and Lal, 2005).

The aim of this study was to address environmental issues related to livestock that have not received due attention they deserve. Environmental legislative actions are usually taken after events have created serious damage to the environment. It is obvious that there are threats to ecosystems as well as mitigation and opportunities to be adapted. The previous approaches by governments of responding to problems by donating food aid and health services, limited the capacity of local communities to adapt. The emerging new opportunities are taken as soon as possible to put producers and other actors in the value chain at a better competitive advantage.

In the short term, improved management by intensifying "best practice" will have mitigation effects. This can be undertaken through improved quality fodder production and feeding systems, as well as stock balancing based on available feed and water resources. Intensification of animal production and mechanization of agriculture will help to reduce dependence on large number of animals for a stable output. Release of crop varieties that have high food and feed value, and better forage management based on the agro-ecological suitability will help to increased biomass production that can satisfy the animal feed demand (Mendelssohn and Dinar, 1999). The alternative is to find options and discover what already exists such as adaptive breeds to the climate and forage varieties which are better adapted to the changing environment. Options such as changing land uses and farming systems have to be considered. Seasonal weather forecasting and early warning systems will help in decision-making, preparing for whatever impacts of increased or decreased rainfall may have on feed supplies, disease, and marketing; in order to adjust herd management for restocking or destocking (NMSA, 2001; Deressa and Hassan, 2009).

In the long term, adaptation will be the key to success against climate change. Vulnerability to climate change can be reduced by preparing, evaluating and implementing adaption strategies that reduce negative threats, while fostering the positive opportunities (NMSA, 2001; Deressa and Hassan, 2009). Governments, civil societies, non-governmental organizations and the private sector need to work hand in hand with local communities to implement the proposed mitigation measures (Hassan, 2010). Sound policies will help in the reduction of disputes in greenhouse gas emissions, drought, water and pollution; and encourage development, evaluation and adoption of effective strategies to environmental change (Deressa, 2007).

In addition, effective natural resource management has a strong impact and is vital in ensuring community social, economic and environmental wellbeing (Deressa and Hassan, 2009). It is with this background in mind that in 1992 world leaders reached an agreement to protect the global climate by signing the United Nations Framework Convention on Climate Change at the Earth Summit in Rio de Janeiro (UNFCCC, 1997). The ultimate objective of the UNFCCC was to stabilize the concentration of greenhouse gases in the atmosphere at a safe level. The Kyoto protocol was adopted in Kyoto, Japan on 11 December 1997 and was ratified on 16 February 2005. The detailed rules for the implementation of the protocol were adopted in Marrakesh, Morocco in 2001, and were then referred to as the "Marrakesh Accords." The first commitment period started in 2008 and ended in 2012 (UNFCCC, 2013).

The "Doha Amendment to the Kyoto Protocol" was adopted in Doha, Qatar on 8 December 2012. The amendment included new commitments to the Kyoto Protocol from countries which agreed to commit themselves for the second period from 1 January 2013 to 31 December 2020. During the first commitment period, 37 industrialized countries and the European Community committed themselves to reduce GHG emissions to an average of 5% compared to the 1990s levels. During the second commitment period, countries agreed to reduce GHG emissions by at least 18% below the 1990s levels in the 8-year period from 2013 to 2020 (UNFCCC, 2013).

The purpose of this study was therefore to make up for the lack of information on the interactions between livestock and environment by assessing the relationship between livestock, soil, water, land, climate, crop and human related influences under mixed crop-livestock production systems in the central Ethiopian highlands; and come up with some practical recommendations. The study was also to highlight future research direction in livestock and environment interfaces under small-scale agriculture in developing countries.

1.2 Problem statement

In central Ethiopian highlands, negative livestock-environment interaction impacts are mainly associated with overgrazing and land degradation (de Hann *et al.,* 1998; Steinfeld *et al.,* 2006). Overgrazing causes chemical and physical soil degradation (Steinfeld *et al.,* 1998; Steinfeld *et al.,* 2006), which reduces plant cover and causes soil compaction. It reduces infiltration and increases run-off that decreases soil fertility and organic matter content, all of which contribute to physical and chemical land degradation. Moreover, socio-economic changes in the rural areas such as population growth, has led to a decline in household land size, forcing people to turn to cultivating crops on steep mountain slopes and pushing livestock to marginal areas, which enhanced land degradation even further (FAO, 2006; Lal, 2006). Socio-economic changes in rural areas also induced community adoption of new practices and new income generation options to sustain their livelihoods. Economic growth and population increase in urban areas attracted investment in intensive livestock production to meet the growing demand for animal protein (World Bank, 2010)

The dynamic social and economic changes in urban and rural areas contributed to gradual changes in traditional livestock practices in mixed crop-livestock production systems. The challenge, however, was how to balance between the increase in livestock population and livestock productivity per head, while reducing livestock induced environmental problems (Delgado *et al*., 1999). In the current study area there were two livestock production systems: (a). Mixed crop-livestock production system mainly operated by small holder subsistence farmers, and (b). Intensive livestock production system operated by large-scale commercial livestock farms as well as mid-scale urban and peri-urban farms.

In the mixed crop-livestock production system, crop production is the major source of cash income (Amare, 1980; MoA, 2000) and farmers sell part or all of the grain and straw produced on-farm to cover other living expenses. Livestock play an important role as a source of power for crop production and manure as organic fertilizer, household fuel and cash income. It serves as a living bank and provides income and food for households (Hadera, 2001; Tesfaye *et al.,* 2004). However, no detail study has so far been done on the contribution of manure as means of household income and its value in the market chain. The shift in the use of manure as a fertilizer to a source of fuel and extra income became evident very recently, because of: (a) continuous deforestation for firewood (Tesfaye *et al.,* 2004), and (b) increased level of poverty in the rural areas that compelled households to sell manure for extra income (Gryseels, 1988).

The vast majority of small-scale farmers in central Ethiopian highlands have abandoned nutrient recycling through manure, to compensate for lack of access to chemical fertilizer (Tesfaye *et al.* 2004). The traditional practice of adding manure to the soil and allowing crop residues to decay in the fields has also dropped (Kahsay, 2004). Nutrients are removed from the soil through plant root systems, transformed to plants tissues and exported in the form of grain and straw outside the farms without any or little replacement. Therefore, organic matter content in the soil is diminishing very fast. Farmers rely on commercial fertilizer to meet crop needs for nutrients (IPMS, 2004). Some of the soil types in the study area had enough soil nutrients to meet crop needs over short term, but over the long-term large off-farm fertilizer inputs would be required to maintain soil nutrient balance and crop yields. The current prices of commercial fertilizer are beyond the reach of resource-poor farmers, which will force some farmers to drop the use of fertilizers (Endale, 2011). Thus, mixed crop-livestock production systems are in crisis because of: (a). Changes in socio-economic status has forced farmers to drop the traditional agricultural practices and adopt other livelihood options (b). Lack of promotion of scientific technologies meant to intensify crop-livestock production at subsistence level as expected (Alemu, 2002).

The impact of livestock on land degradation is a serious problem unless proper stocking rates, management and proper land uses are enforced. Livestock rearing has to be considered as a business enterprise by small-scale farmers for sustainable and environmentally friendly development (Azage, 2002). Intensive livestock operations often have inadequate land base to efficiently use all they generate, so there is increased risk of water contamination and health hazards (Yoseph *et al.,* 1999; 2002). Excess use of manure in some fields can also create toxicity to plants, water and eventually affect productivity (Tesfaye *et al.,* 2004). Thus, there was an imbalance of nutrient flow in intensive and extensive livestock production systems in the study area.

In spite of the economic importance of livestock production in Ethiopia, there is very little or no information about the interactions of livestock and environment in relation to climate change and the impact on livestock production. The only exception is the work done by Steinfeld *et al.* (2006) and de Hann *et al.* (1998) on global livestock and environment interactions, otherwise there is no other information on specific aspects of environmental and livestock interactions at regional and country level, particularly under small-scale farming.

This study is anticipated to fill in the gap in the literature by examining the impact of environment on livestock and in vice versa; using household socio-economic survey, biological data of soil and water laboratory analysis, secondary data from weather stations and different crop forecast models. This study intended to assess the interrelationships of livestock, soil, water, land, climate, crop and humans under mixed crop-livestock production systems; and to come up with recommendations that could assist in forming environmentally friendly livestock production systems. It also envisioned generating future research topics that could be used by the scientific community to develop strategies to combat the effects of climate change and other environmental consequences.

1.3 Research aims and objectives

The aim of this study was to determine the magnitude and intensity of livestock, soil, water, land, climate, crop and human interactions in the central Ethiopian highlands, with emphasis on the Ada district by using methodology that integrated socio-economic data and biological information with reference to secondary data.

Therefore, the objectives of this study were:

1. To assess the effect of change in land management on carbon storage and the contribution of livestock to carbon storage.
2. To examine the impact of livestock on natural resources and the environment.
3. To assess the effects of the change in traditional agricultural practices, expansion of factories, slaughter houses, greenhouses and flower farms on water and soil quality.
4. To evaluate the effect of climate change on livestock production under small-scale agriculture.
5. To recommend options for mitigation and adaptation to environmental changes.

1.4 Significance of the study

The farming communities would be made aware about imminent climate changes and the likely impacts on their livelihoods. Local and national government bodies would also need to understand climate change hazards and prepare for mitigation and adaptation options.
Livestock farmers should be made to understand that livestock keeping has negative consequences on the environment if not properly managed. Livestock production contributes positively to carbon storage and negatively to climate changes through improper land uses, degradation, greenhouse gas emissions and the pollution of land, water and air. In order for communities to survive, they need to adapt to environmental changes and respond appropriately.

Expansion of processing industries, flower farms and abattoirs produce chemical discharge into the soil and water bodies that are used by livestock and people.

Documentation and monitoring of the level of chemical discharges before they reach hazard levels is important. Establishment of appropriate policies and institutions that trades-off environment and livestock to avoid the level of damage on environment as well as documenting the influence of global climate change on livestock production is vital. Accordingly, there is a great need to assess the relationship of livestock, land, water, soil, crop and human related issues under small-scale farming to recommend how to balance these relationships.

1.5 Outline of the study

Chapter 1: provides the background on climate change, livestock and environment interactions. It stipulates the problem statement and objectives and the significance of the study.

Chapter 2: focuses on livestock and environment interactions. It specifies the impacts of livestock on environment and vice versa. It also explores the effect of climate change on agriculture and the adaptation measures for livestock production in Ethiopia.

Chapter 3: presents the study area, the materials and methods used in data collection and analysis.

Chapter 4: investigates alternative land management practices for carbon sequestration and the role of livestock in mixed crop-livestock production systems in Ethiopian highlands.

Chapter 5: examines manure use and management under small-scale agriculture and their impacts on the environment.

Chapter 6: explores water quality for livestock in urban and peri-urban areas in Ethiopia.

Chapter 7: investigates heavy metal contamination from industrial waste and its impact on environment and livestock production.

Chapter 8: explores climate change on livestock production in central Ethiopian highlands and discusses the extent of awareness of climate change in the study area. It further investigates the choice of adaptation measures and factors that affect the choice of adaption measures.

Chapter 9: summarizes, concludes and makes recommendations based on the findings of the study.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Global climate change is one of the most significant environmental challenges in the world. The intergovernmental panel on climate change (IPCC, 2007) has indicated that global warming due to climate change could lead to many environmental threats i.e. drought, floods, sea level rise, decline in crop and animal production, and health hazards, among others. Greenhouse gases (GHGs) are released in the atmosphere both from natural sources and anthropogenic (human related) activities. However, during the past few decades, the amounts of GHGs released into the atmosphere due to human activities have increased significantly (FAO, 2006).

The impact of climate change on animal production has been broadly categorized as direct and indirect effects (Naqvi and Sejian, 2011). The direct effects are absolute outcomes observed in animals such as heat stress due to the increase in ambient temperature, reduced feed intake and abnormal physiological process, change in animal behavior and metabolism, stunted growth, reduced productivity, and reproductive malfunction. The indirect effects of climate change are due to the change in animal environment such as reduced feed quality and quantity, reduced water resources and quality, increased severity and distribution of diseases and parasites, financial losses due to the cost of production and animal performance (Hansen, 2004). Both the direct and indirect effects of climate change result in a decline in production and reproduction performance of livestock.

There are some livestock species which can thrive well under harsh climate conditions either due to natural selection or through human genetic improvement programs (Jahnke, 1982). Natural selection is a biological adaptation process that requires a long period and changes happen slowly (Solomon, 2000). Humans interfere with natural adaptation processes by adapting animals and plants through domestication and selective breeding. Hansen (2004) reported that *Bos indicus* cattle breeds of the tropics are capable of regulating body temperature in response to heat stress much better than *Bos taurus* cattle breeds of European origin. The superior ability of regulating body temperature during heat stress is the result of lower metabolic rates as well as increased capacity for heat loss. Once specific genes that are responsible for thermo tolerance in *B. indicus* cattle have been identified or mapped, breeding strategies such as marker-assisted selection and transgenic tools can be applied for further exploitation of *B. indicus* genotype for cattle production systems under increased temperature or heat stress condition (Hansen, 2004).

There are different means of adaptations to environmental change such as migration. Gray and Muller (2011) investigated the effects of drought on the labor and marriage-related mobility of men and women over a ten-year period in Ethiopia. Migration of birds and wildlife is also common when there is an ecological imbalance, and natural resource base is no longer able to support them, on the one hand, and on the other hand, climate change affects the migratory trends of birds and animals (Robinson *et al.,* 2005). For instance, increased drought is likely to extend the width of deserts which are currently significant barriers to migratory birds. This affects the ability of Afro-European migrant birds to fatten sufficiently before they cross the deserts (Robinson *et al.,* 2005). The habitats that migratory birds depend on are in danger of changing or disappearing due to increasing desertification, flooding and rising temperature. Migratory birds are particularly vulnerable because of their use of several habitats during migration as stopover sites for feeding, resting and pastime during bad weather (Robinson *et al.,* 2005).

The classical way of thinking about climate change and its effects is about people, but it may also affect other living creatures too, such as wild plants and animals (FAO, 2011). Some wildlife species are adapting to the changing climate already by migrating earlier or later than usual, or by extending their migration patterns in search of suitable habitats. However, not all animals are capable of acclimatizing fast enough. For example, there is concern by environmentalists about the decreasing population of amphibians and reptiles (FAO, 2011). Wildlife populations are linked together in a food chain. When smaller animals fail to thrive, there is less food available for the larger animals. Through the web of life, factors that damage one population will eventually have an impact on other populations even to humans and livestock. Altizer *et al.* (2011) reviewed about how the long distance migrating wildlife can cause disease threat to humans and livestock. The reviewers reported that the deadly Ebola outbreaks in the Democratic Republic of the Congo have been linked to an influx of migratory fruit bats. In the future, shifts in natural migration patterns may change the places and how such disease outbreaks could occur. Destruction of habitats by urbanization or agriculture can eliminate stopover areas forcing more animals to fly to the remaining few sites. This in turn could create hotspots for disease transmission. The human encroachment on these natural sites could also increase the risk of contact with infected animals (Altizer *et al.,* 2011).

Animals that are hardy and adapted to reference climate conditions may thrive well while others may move to more suitable regions (Naqvi and Sejian, 2011). Livestock adapted to hot environments will be preferred in hot semi-arid and arid regions. Thus, climate change may result in a decrease or increase in populations of a livestock species in many regions (Moss *et al.,* 2000; IPCC, 2007). Natural selection of livestock species to particular environments is the other adaptation strategy to climate change (Gaughan *et al.,* 2009). Camels, sheep and goats are believed to be less susceptible to environmental stress than other livestock species (Tezera *et al.,* 2010). These animals have unique characteristics such as higher water conservation ability, higher sweating rate, lower basal heat metabolism, higher skin temperature, constant heart rate and constant cardiac output. They compensate adaptation to harsh environments at the cost of lowering performance such as growth, production, metabolism and reproductive performance (Hansen, 2004).

The livestock genetic improvement programs in the 20th century targeted increased productivity that has resulted in animals that are susceptible to heat stress, feed scarcity, diseases and pests (Hansen, 2004). Differences in the resistance of livestock to different harsh environments could allow for selection within and between breed and species that are suited to particular environmental conditions. Exploiting the genetic merit of the wild relatives of these animals may be another option (Hansen, 2004). However, the selection of such animals may result in an improved welfare and ability to cope with harsh environmental conditions at the expense of productivity (Gauhghan *et al.,* 2009). Mitigation of livestock to climatic stress becomes necessary if high producing and less tolerant livestock are to be reared in harsh environmental conditions.

2.2 The demand for livestock products in Ethiopia

The future demand for livestock products in Ethiopia will be mainly affected by two factors: population growth and socioeconomic scenarios. The current population of 85 million is dominated by young people at nearly 50% of the people under 14 years of age and the population is growing at the rate of 3.2% a year (MoFED, 2011). At the current pace of growth, the population is expected to be more than double by 2050 (NMSA, 2001). It has predicted the population growth till 2030 based on three variables obtained from the response level of the Ethiopian community to family planning and modernization. The variables are categorized as low, medium and high variants, which estimated the human population of Ethiopia to reach 118.1 million, 129.1 million and 149.4 million respectively by 2030.

The future climate change will occur in a changed socioeconomic condition, too. These changes are challenged by growth in per capita income, adaptation of changes by Ethiopian society in their culture, societal infrastructure development and global technology growth. The cultural change includes transforming into more secular society (renovating religious sect) and thus consumers' taste and preference change. Badada (2000) set economic indicators such as GDP gross, growth rate and per capita, for low, medium and high scenarios. The author estimated the GDP growth rate from 2000 to 2030 to be in the range of 3.5 - 4.2, 4.7 - 5.8 and 6.0 - 7.6 for low, medium and high economic growth scenarios, respectively.

Assuming a high economic growth rate in Ethiopia with a GDP growth rate of between 6 and 7.6% per annum until 2030, the anticipated per capita consumption would be 154 kg for cereals, 14 – 20 kg of meat and 40 – 60 kg of milk per year (Badada, 2000). Taking into account medium population growth rate and the highest economic growth rate; to satisfy the consumer demand in 2030, Ethiopia needs to produce 2.2 million tons of meat that is triple the current production and 6.5 million tons of milk that is four times the current milk produced (FAOSTAT, 2012). However, to satisfy the demand there are many other options such as; (a) Increase in productivity per animal through intensive farming, (b) Increase in livestock population through extensive management under the existing situation, (c) Importation of animal products, (d) A combination of all the above options. The second and third options are not recommended under the current technologies and socioeconomic changes.

Even without the increase in the demand of meat and under a medium population growth rate scenario, the demand for meat will double by 2030, while the demand for milk will triple. That means there has to be an increase in cereal production for human and animal consumption of about 22 tons by 2030, which is more than twice the current cereal production level of 12 million tons per annum (FAOSTAT, 2012).

2.3 Climate change scenarios in Ethiopian context

Records based on historical data from 1961 to 1990, showed that the rainfall pattern has remained constant on average over the whole country, although there is a decline in the north and southwest, and an increase in central Ethiopian highlands (NMSA, 2001). The average annual minimum temperature has increased by about 0.25^{o}C every decade, while average maximum temperature has increased by about 0.1^{o}C during the same period (NMSA, 2001). For climate change scenario analysis, NMSA (2001) used three equilibrium and one transient General Circulation Models (GCMs), namely; Canadian Climate Center Model (CCCM), Geophysical Fluid Dynamics Laboratory model (GFDL), the United Kingdom Meteorological Office-1989 model (UKMO-89), and GFDL-Transient model; in addition to outsourced incremental scenarios.

The result of models analysis showed that projections for rainfall did not manifest a systematic increase or decrease. The GFDL model gave 10-20% increase for the major rainy season for places north of 8° latitude and west of 41° longitude. CCCM model projected an increase by about 50% for extreme northern areas, while the transient model projected a decrease. An increase of 5% of the short rainy season was projected for southwest, south and southeast parts, while a decrease was expected for the northern parts by all models (NMSA, 2001).

2.4 Impacts of climate change on agriculture in Ethiopia

NMSA (2001) used the three equilibrium and one transient GCM models to predict the impact of climate change on crop production for two crops (wheat and sorghum), in different agro-ecological zones by using DSSAT crop simulation model. The models generally predicted a decrease in maturity period and yield for wheat except CCCM climate model which predicted yield increase. In the case of sorghum the model predicted an increase in potential grain yield, because of above ground biomass and improved nitrogen uptake as input level increased. The results show that when there is a climate change, there is room for adaptation by changing farming systems and management (sowing time, seed rate, fertilizer application, etc.), adapting suitable crop varieties and types, changing crop agro-ecology, promoting irrigation and natural resource management. Fischer and van Velthuizen (1996) suggested that temperature rise may have a negative effect in many lowland and semi-arid zones while highland areas will benefit.

Deressa and Hassan (2009) used Ricardian model to analyze the impact of climate change on crop farming based on household interviews and weather station data. The results showed that marginal increase in temperature during winter and summer seasons reduced the net revenue per hectare, while the marginal increase in temperature in the spring and autumn seasons increased the net revenue per hectare. The reason for an increase in revenue was that spring is the planting season in Ethiopia, thus a slightly higher temperature to the level of precipitation enhanced germination and viability. Autumn is when crops mature; hence, moderately increased temperature enhanced maturity and reduced losses. Likewise, increased precipitation in spring improved germination and yield, while increasing precipitation and temperature in winter (dry season) reduced the yield and net revenue per hectare due to favorable environment created for pests and diseases. Marginal increase in precipitation in summer and autumn reduced net revenue per hectare due to flooding, compaction, weed invasion, disease and pest outbreak and erosion.

The impact of future climate change on crop production was also analyzed by Deressa and Hassen (2009) using uniformly changed temperature and precipitation scenarios as well as by applying predicted values of temperature and rainfall from three climate change models (CGM2, HaDCM3 and PCM). All models predicted increases in temperature and precipitation for the years 2050 and 2100, except CGM2 model which predicted a decrease in precipitation for 2050 and 2100. Results showed that all the climate change models forecasted an increase in net revenue per hectare by 2050, whereas by 2100 it would decrease.

Climate change impact studies in Ethiopia focused either on the economy or on the crop agriculture sector but did not give due consideration to impacts by agro-ecology and livestock agriculture (Zenebe *et al.,* 2011). These authors analyzed and estimated marginal effects of the climate variables on crop/livestock/farm net revenue per hectare. Net revenue per hectare was reported different for temperature and precipitation and also for crop, livestock and mixed agriculture. An increase in temperature (PCM, HadCM3 and CGM2), an increase in precipitation (HadCM3 and PCM) and a decrease in precipitation (CGCM2) reduced incomes obtained from crop, livestock and mixed agriculture for 2050 and 2100. The decline in income was similar to uniform climate scenarios (increasing temperature and decreasing rainfall). However, the impact of climate change due to temperature increase affected crop production more than livestock, while reducing rainfall severely affected livestock more than crop production (Zenebe *et al.,* 2011) when considered under most of climate change forecast models and scenarios. Under a uniform forecasted climate change scenarios, i.e., an increase in temperature by +ve2.5^{o}C and +ve5^{o}C and a decrease in precipitation by –ve7% and -ve14%, has a significantly affected crop production more than livestock. Zenebe *et al* (2011) also forecasted temperature and precipitation for 2050 and 2100 based on agro-ecology but it failed to depict the wider climate variation that exists across the country and unfairly predicted temperature and rainfall change across the agro-ecology as insignificant.

More than 95% of total livestock in Ethiopia thrive under extensive livestock management systems. The major livestock feed sources are crop residue under mixed crop-livestock production systems in the highlands and pasture under lowland pastoral livestock production systems. There has been frequent drought and a decrease in annual rainfall over the last few decades, which diminished the biomass yield of pasture and crop residues (Gray and Muller, 2011). Pasture and crop-residue quality have deteriorated due to climate change and total availability of feed and fodder resources are constantly scarce. In some areas C_3 grasses of high nutritive value are being replaced by lower quality C_4 tropical grasses (Barbehenn *et al.,* 2004). Disease and vector expansion, water resource availability and quality are among the climate change challenges that may seem to be on a downward trajectory.

2.5 The role of livestock in climate change

The weather data show that an increase of 1°C makes the earth hotter now than it has been for the last hundreds of years (IPCC, 2007). It is not only about how much the earth is warming, but also about how fast it is warming and what will be the future. Although global warming is quite natural in human history for thousands of years, the fast and high temperature rise over the last 100 years has never occurred before (IPCC, 2007). The increasing global atmospheric temperature has been attributed due to an increase in the concentration of greenhouse gases in the atmosphere, an occurrence known as global warming (FAO, 2006). Indeed, average global temperature has risen considerably, and the IPCC (2007) predicts increases of 1.8 - 3.9ºC by 2100.

The greenhouse gas emissions from the agricultural sector contribute about 25.5% of total global radiation and over 60% of anthropogenic sources (IPCC, 2007). Livestock production accounts for 18% of GHG emissions that cause global warming (FAO, 2006). Methane (CH_4) contributes the largest greenhouse gas emission which is almost equivalent to other non-CO_2 GHGs combined (Kulling *et al.,* 2003). Although atmospheric concentrations of GHGs have increased by about 39% since pre-industrial era, CH_4 concentration has increased more than double during the same period (WHO, 2009). Reducing the increase of GHGs emissions from agriculture, especially from livestock production should therefore be a top priority, because it could limit global warming substantially and faster (Sejian *et al.,* 2010).

Methane is considered to be the largest potential contributor to the global warming phenomenon (Steinfeld *et al.,* 2006). A significant amount of the global GHG emissions currently comes from enteric fermentation and animal manure from traditional smallholders mixed farms in developing countries (FAO, 2006). Furthermore, the effects of climate change may lead to global warming and the rise of the sea level (Gaughan *et al.,* 2009). This may lead to outbreaks or spread of many infectious diseases, increase in the incidences of heat stroke and livestock diseases due to air pollution (Altizer *et al.,* 2011).

2.5.1 The role of methane in GHG inventory and climate change

Methane is one of the primary greenhouse gases and second only to CO_2 in generating greenhouse effects. It is 21 times more effective in trapping heat than CO_2 on a weight/weight basis (Moss *et al.,* 2000). It has a short atmospheric life span of 10-12 years compared with 120 years for CO_2 (IPCC, 2007). Natural sources such as wetlands, termites, ocean fresh water and gas hydrates contribute about 30% of total global methane emissions (West *et al.,* 2006). The rest (70%) comes from anthropogenic activities like livestock rearing, rice/paddy cultivation, natural gas and petroleum processing and use, coal mining, landfills, livestock manure, wastewater treatment etc. (FAO, 2006). The reduction of methane may lead to rapid benefits and recovery from greenhouse gas emissions. Currently, cost effective technologies have been developed and are available for the control of most anthropogenic methane emissions (Reilly *et al.,* 2003).

Methane from agricultural sources: More than 50% (about two thirds) of global anthropogenic methane emissions were caused by agricultural practices. The major sources of agricultural emissions of methane are ruminants, rice cultivation, handling and processing of livestock manure and biomass burning (FAO, 2006).

2.5.2 The contribution of ruminants to GHG through enteric-methane emission

Ruminants such as cattle, buffaloes, sheep and goats contribute the largest proportion of the total agricultural emissions of methane (Gaughan *et al.,* 2009). Ruminants are characterized by the presence of a rumen, which is a special digestive organ in the body (Jahnke, 1982). Besides having a unique ability to digest fibrous and low grade roughages, the rumen is also a major producer of methane, a potent greenhouse gas (FAO, 2006). The enteric fermentation in the rumen is very useful because it converts coarse and fibrous roughages to absorbable nutrients. However, enteric fermentation in the rumen also produces methane through bacterial breakdown of feeds through a process called methanogenesis.

Ruminant animals release methane into the atmosphere through exhaling or ruminating through the mouth and nostrils (Berhanu, 2006). Enteric fermentation also produces volatile fatty acids. Among the volatile fatty acids, acetic and butyric acids promote methane production. Global emissions of methane from the digestion process in ruminants is in the range of 70-220 million tons per year (Reilly *et al.,* 2003) and is considered to be the largest source of anthropogenic methane emissions (IPCC, 2007). Methane from ruminants can be managed for the reduction of methane emissions (West *et al.,* 2006).

NMSA (2001) carried out greenhouse gas inventory in Ethiopia in order to identify the principal sources of emissions and to establish quantitative estimates of the emissions from different sources in the country. The five emission sectors were categorized as: energy, industrial processes, agriculture, land use change and forestry and waste material. Emissions of six gases were identified from these sectors including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), nitrogen oxide (NO), carbon monoxide (CO), non-methane volatile organic compounds (NMVOC) and sulfur dioxide (SO_2) for 1990 to 1995. Emission factors recommended by the IPCC (1996) were adopted in greenhouse gas inventory in order to quantify the emission volume of each gas.

According to NMSA (2001), the total CO_2 emissions in Ethiopia, excluding the land use change and forestry (LUCF) sector, were estimated at 2 596 Gg in 1994. About 88% of CO_2 emissions came from fossil fuel combustion in the energy sector, which is the main emitter of CO_2 within the sector. The industrial processes sector contributed 12% of CO_2 emissions mainly as a result of cement factories. In 1994 biomass burned for cooking and warming, mainly in domestic households, released about 66 757 Gg of CO_2. This amount was not included in national CO_2 emissions inventory as per the IPCC recommendation. Because IPCC (1996) assumed that biomass resources were consumed on a sustainable basis, a balance of emissions and sink. For example, fuel wood burned in one year but re-grown in the next, only recycles carbon rather than creating a net increase in total atmospheric carbon. The country's stock of natural forests, woodlands, shrubs and plantations sequestered about 27 573 Gg of CO_2 in 1994 while emissions of CO_2 were estimated to be 12 510 Gg in the same year as a result of deforestation. Therefore, the net carbon balance of the land use change and forestry (LUCF) sector was a net sink in 1994, which amounted to about 15 063 Gg of CO_2. This amount is a balance between change in forest and other woody biomass stocks and forest and grassland.

The role of livestock in methane production: Although there is a huge livestock population of 98.9 million heads in Ethiopia **(Table 2.1),** livestock systems are small contributors to greenhouse gas emissions **(Table 2.2)** resulting in about 1.76 million tons of methane per year. The global methane emissions from all sources have been estimated at 500 - 600 million tons/year (IPCC, 2001). The estimated values of methane emissions from domestic animals varied widely in different reports from 70 to 220 million tons/year (Reilly *et al.,* 2003). The large variation was attributed to the methodology adopted and assumptions made in estimating the emission rate per animal.

Table 2.1: Ruminant population in Ethiopia

Species	Ethiopia (mil)	World (mil)	World (%)	Ranking in the world
Cattle	50.90	1334.50	3.80	
Goats	26.0	780.10	3.30	
Sheep	22.0	1038.76	2.12	
Total	**98.90**	**3326.06**	**2.97**	**10^{th}**

Source: FAO (2006) for world ruminant population and FAO Stat (2012) for Ethiopia

Livestock production systems play a significant role in the Ethiopian economy by contributing a large amount of draught power and food (milk meat and eggs); fiber (wool, costumes); hides, skins and manure. Methane emission from enteric fermentation is about 1.76 million tons per year **(Table 2.2),** which was in the range of 0.3 to 0.35% of the global methane emissions. More than 84% of the total methane emission from enteric fermentation was from large ruminants and the rest from small ruminants and equines (**Table 2.2**). The amount and type of feed consumed and digested were two important sources which contributed to the total methane production (Berhanu, 2006). Methane production per animal in developing countries was relatively much lower than the values reported for the animals in developed countries. This was accredited to body size of the animal and the amount of feed provided to the animals (Berhanu, 2006). On average, cattle in developing countries produced about 28-35 kg methane per annum compared with 55 kg methane/annum for cattle in the developed world (FAO, 2006).

Table 2.2: Methane emissions from livestock

Ruminants	**Methane emissions (kg/animal/year)**	**Tons (mil)**	**(%)**
Cattle	28.84	1.47	83.50
Goats	3.92	0.10	5.70
Sheep	2.88	0.07	4.00
Others*	20.00	0.12	6.80
Total	**55.64**	**1.76**	**100.00**

*Camels, horses, ponies, donkeys, and pig; **Source:** Singhal *et al.* (2005)

Although the current level of methane emission from livestock sector in developing countries is not a threat to global warming, the current fast economic and human population growth could drive the increase demand for animal protein, which may attract more investment in intensive agriculture, and lead to high methane emissions. Therefore, future strategies and research efforts should be directed towards mitigating methane emissions.

2.5.3 Mitigation strategies for methane emissions

Several alternatives for mitigating methane production and plummeting emissions into the atmosphere by livestock have been proposed (Reilly *et al.,* 2003). The amount of methane production from the rumen and the total release of methane into the atmosphere can be reduced through the introduction of appropriate technologies. All alternatives suggested either the reduction of methane production per animal or per unit of animal product (Johnson *et al.,* 2002). Sejian *et al.* (2010) described the factors to be considered for the selection of the best alternatives for the reduction of methane emissions including climate, economic, technical and material variables, existing waste management practices, and regulatory requirements. Methane mitigation strategies can be grouped under three broader categories such as management, nutritional, and advanced biotechnological strategies (Sejian *et al.,* 2010).

Methane gas has a relatively short shelf life (10-12 years) in the atmosphere as compared to other greenhouse gases such as CO_2 which has a shelf life of 120 years (IPCC, 2007). Therefore, due to its short shelf life, the strategies for the reduction of methane in the atmosphere should be a practical means of slowing global warming (Turnbull and Charme, 2001). Lelieveld *et al.* (1993) estimated that decreasing the emission rate by only 10% will stabilize the methane concentration in the atmosphere to current level. The mitigation strategies for reducing enteric methane production from ruminants are summarized in **Table 3** below.

Table 2.3: Strategies to reduce methane emissions from livestock

Strategies
• Improved genetic selection to produce low methane producing animals. • Efforts must be taken to reduce livestock population. • Improved nutrition by providing high quality feed and strategic supplementation of essential nutrients. • Improving grassland management. • Ensuring proper health and care through upgraded veterinary practices. • Increasing the proportion of concentrate feeding. • Diet modification through ammonia and molasses feeding to reduce methane. • Oil and ionophore supplementation e.g., monensin and tannin. • Defaunation and rumen microbial intervention. • Reducing the manufacture of livestock products. • Employing advanced technology like immunization and recombinant technology for reducing methane production.

Source: Sejian *et al.* (2010)

2.6 Environmental problems associated with livestock and humans

Land use change: High population density in large areas of the country has created negative effects on agricultural production and environmental security. The per capita land holding declined from an average of 1.76 ha in 1985 to 1.1 ha in 2000 and is expected to decline further to an average of 0.66 ha in 2015 (IUCN, 1990). Average farmland per household in the southern highlands has already decreased to less than 0.25 ha (MoFED, 2006). This has led to severe competition in land use between crop, grazing and forest lands. It is evident that so many meadows in the flood plains have been converted to croplands (Kahsay, 2004). In addition, due to the clearing of vegetation for cultivation, many steep areas have become vulnerable to wind and water erosion. Important browse that serve as dry season feed have been used for construction and fuel (Alemayehu, 2005). The change in land use has adversely affected the availability of grass and shrubs, leaving livestock herds poorly nourished and prone to low production, low reproduction and diseases as more land is allotted for cultivation and other purposes.

Overgrazing and land degradation**:** The simultaneous increase in both human and livestock populations brought the depletion of biological resources. This in turn forced livestock to move to the upper slopes in search of feed or to concentrate on the small natural pasturelands and roadsides. This caused overgrazing and soil erosion, which eventually led to land degradation. Cow dung which could have been used to enrich soil is consistently collected and used for household energy requirements (Halderman, 2004; Kahasye, 2004; Tesafye *et al.,* 2004).

In the highlands, it was reported that livestock affects the physical properties, moisture content and infiltration rate which led to increased soil erosion (Bojo and Casells, 1995; de Hann *et al.,* 1998). The actions of animal hooves especially, the small cloven hooves of sheep and goats destroy vegetative cover which exacerbated land degradation (Steinfeld et al., 2006). Heavily grazed plots were found to have a lower species composition than medium grazed ones (Taddese and Peden, 2003).

Emission of gases from livestock: Animal husbandry results in CH_4 emissions from two main sources: enteric fermentation (the digestive processes of animals) and waste management. The estimated total amount of CH_4 emissions from enteric fermentation in 1994 was about 1337 Gg, accounting for 80% of the total national emissions, which dung used as a fuel released 49.5 Gg CH_4 per annum (NMSA, 2001). Global livestock and waste management contribute about 16% of total annual CH_4 production (FAO, 2006). It is obvious that Ethiopia's contribution to the global emissions of GHGs is negligible. However, it has been noted that there was a general increase in GHG emissions in Ethiopia in the period between 1990 and 1995 and it was expected to increase in the future along with socioeconomic development and population growth (NMSA, 2001).

Reduction of domestic animal diversity: Commercialized and mixed livestock production systems use a very limited range of animal breeds (Azage and Alemu, 1997). This has already led to the extinction of some local livestock breeds and genetic erosion of others (Nigatu *et al.,* 2004). Specific genetic merits in local breeds that cope with the climatic, nutritional and disease challenges may already have been lost (Schneider, 2006).

Soil and water pollution: Intensive livestock production creates enormous pollution problems because it brings in large quantities of nutrients in the form of concentrate feeds and then it has to dispose of the waste in nearby residential areas (Azage and Alemu, 1997), which quickly become saturated. As a result, land and ground water become polluted. The human health hazard from poor waste disposal in residential areas is a serious problem (Schneider, 2006).

2.7 The impacts of environmental changes on livestock production

***Climate change and its impact on livestock production*:** According to NMSA (2001) the climate in Ethiopia is mainly controlled by the seasonal migration of the inter-tropical convergence zone (ITCZ) and associated atmospheric circulation as well as by the complex topography of the area. Previous studies at international and regional level have proved that natural and human-induced climate variations ranging from short-term i.e., seasonal to inter annual variability due to El Niño Southern Oscillation (ENSO), to long-term changes (i.e., temperature shifts and sea level rise associated with greenhouse warming) may have a significant impact on water resources, grasslands and livestock, crops and forests, physical aspects of the coastal zones and even on human health (NMSA, 2001). Studies by NMSA (2001) have shown that there is a link between El Nino and La Nina phenomena and rainfall in Ethiopia. As a result, the associated occurrence of extreme events like floods, droughts and severe weather conditions, as well as the steady change in average climatic conditions are currently matters of concern.

Evidence that could be associated with climate change has already started to appear in Ethiopia. In the last 50 years the annual average minimum temperature over the country has been increasing by about 0.20ºC every decade. The country has experienced frequent and extensive droughts in recent decades which caused severe food shortages and famine. The spread of malaria into the highlands which had never experienced malaria before, loss of biodiversity and a decline in wildlife numbers have been observed (Cline, 2007). Recent studies (NMSA, 2007) indicated that the projected changes in the current climate and its variability would have serious implications on natural resources, the economy and the welfare of Ethiopia.

NMSA (2001) conducted an environmental impact assessment using climate change scenarios in Ethiopia, which considered incremental changes by assuming a 2 to 4ºC increase in temperature with changes of ± 20 to ± 10%, respectively, without change in rainfall over and above the 1961/1990 mean rainfall. Based on the temperature incremental change, the impact of climate change was analyzed for wheat in the highlands, and the results showed that the United Kingdom meteorological office-1989 (UKMO) and geophysical fluid dynamics laboratory model (GFDL R-30) projected a decrease in crop maturity from -ve10.6% to -ve18.5%). A decrease in yield was also predicted by the two models, which might be associated with an increase in temperature and may significantly shorten crop developmental stages. The decrease in the yield of wheat has direct and indirect implications on livestock development. The direct impact is that wheat grain and wheat bran are major constituents of concentrate feeds in Ethiopia. The price of concentrate feeds has increased by 25% under the current market prices compared with the 2006 base price (Mekete*,* 2008). The anticipated decrease in wheat yield because of incremental climate change scenario is likely to trigger higher inflation rate for concentrate feeds. The indirect influence is that wheat straw is a major crop residue that is fed to livestock in the highlands (IPMS, 2004). And since the yield of grain and straw are positively correlated, a decrease in grain yield consequently results in a reduction of straw, which aggravates feed shortage at smallholder level.

Climate change would affect grasslands and the livestock sector in many ways such as changes in pasture productivity in quantity and quality (by increasing the lignin content and other unavailable phenolic chemicals), reduce livestock productivity and reproduction, increase in distribution and incidence of animal and plant diseases (NMSA, 2001). For instance, trypanosomiasis used to be a livestock disease in the lowlands in Ethiopia, but recently the disease moved to the highlands due to ecological changes (Markose, 2007). Sutherst *et al.* (1996) carried out an integrated assessment of the socioeconomic impacts of climate change on *Boophilus microplus* (cattle tick) and reported that global warming may result in a wide spread of ticks in both New Zealand and Australia. The cattle tick cause losses in productivity as the vector feeds on blood and transmit tick borne diseases which have a high rate of mortality in cattle that are not adapted.

In general, microorganisms including viruses, bacteria and fungi that are fatal to animals and forage crops, take advantage of climate change (temperature, humidity etc.) to spread and threaten the survival of livestock. Biological mutation of these organisms enhanced by favorable environments could worsen the situation (Cunningham, 1995). The current climate variability and drought are major challenges for the livestock sector and the species biodiversity.

Economic development and environment: With the current increase in population growth, industrialization, urbanization, mining activities, intensified agricultural as well as other developmental activities, there will be the risk for an increase in the number and level of pollutants. It is therefore inevitable that the quality of unprotected underground water will continue to contaminate surface water (GIRDC, 2007).

Industrial pollution and livestock drinking water: The majority of industries in Ethiopia are located along the banks of rivers and streams from where they draw water for their processes (Fisseha, 2002). This contaminated water is used as drinking water for human and animals and it is also used for cooking and other household activities. Most of the high water consuming industries in Ethiopia discharge their waste water directly into the streams and water courses without any kind of treatment whatsoever (Fisseha, 2002). This could be due to either lack of technical knowhow of wastewater treatment plant operations or due to lack of regulations and effective control regarding industrial and domestic effluents by concerned authorities (GIRDC, 2007).

Agricultural pollution and livestock drinking water: Polluting substances introduced as a result of agricultural activities include: inorganic fertilizers, insecticides, herbicides and organic matters. These pollutants enter water bodies mainly through surface runoff and irrigation return flows. Pesticides mostly used include chlorinated hydrocarbons, organo-phosphates and carbonates. Fertilizers in use are basically of nitrate and phosphate origins. Furthermore, control of disease vectors is carried out illegally by using pesticides like dichloro-diphenyl-trichloroethane (DDT) and Lindane whose residues persist for long periods (GIRDC, 2007). These chemicals are toxic and their use has been banned in many countries, including Ethiopia. The majority of people in Ethiopia (75%) do not have access to safe water sources and toilets (World Bank, 2011). In rural areas humans defecate out in the field causing contamination of water and soil by transmittable and fatal parasites and chemicals like nitrogen. Water sources for both human and livestock are rivers, lakes, seasonal floods and ponds, which have the possibility of being contaminated by pollutants (Tamiru *et al.,* 2003).

2.8 Adaptation measures to climate change

Options of livestock technology innovations help to implement alternatives for the anticipated climatic and socioeconomic changes and to recommend preventive measures in the vulnerable livestock systems. The option analysis will establish and demonstrate the importance of applying such innovations and the urgency to implement them in the near future. Such innovations must be based on recommendations that originate from local, national and international experiences based on lessons from government and non-governmental organizations, the results of scientific findings, the experience of community based organizations, as well as local knowledge and reviews of the achievements by other countries. The focus of options for livestock technology innovations is, therefore, on livestock production, input supply and service and marketing, which is trying to satisfy a growing demand without damaging the environment.

2.8.1 Adaptation options for grassland and livestock sectors

It is to be noted that the coping mechanisms and adaptation strategies in which the pastoral communities have been employing for generations are inclusive of using the traditional skill, knowledge and resource management. In general, however, the adaptation strategies commonly practiced can be broadly categorized into three major areas (Beruk, 2000). These are: (a) Improving the survival and productivity level of the livestock and the rangelands; (b) Engagement in obtaining food from other sources and income generating activities in times of crises; and (c) Scaling down of family members and migration for survival. Adaptation options recommended for the sector specifically for the highlands and lowlands are listed below (Beruk, 2000).

Adaptation options for the highlands:

- Selection of crops and cropping systems that maximize biomass production and therefore, CO_2 and N_2 fixation;
- Improved animal genotype and better disease and parasite control to take advantage of the improved management; and
- Use of multipurpose cattle that work and provide milk and meat and also breed to provide suitable draught animals, in addition to supplying fuel and fertilizer from their excreta.

Adaptation options for lowlands/rangelands:

- Strengthening the early warning systems and coping strategies;
- Introduce mixed farming system, where appropriate;
- Destocking of livestock on a regular basis;
- Water resource development in appropriate sites;
- Promote lifestyle choices of pastoralists through access to education and local urban development;
- Rehabilitation of bush encroached areas;
- Conservation and utilization of hay from natural pastures (hay making with local grasses);
- Promotion of herd diversification;
- Promotion of grazing management schemes;
- Use of local legume forage including *Acacia* fruits and leaves;
- Capacity building and institutional strengthening of the local community; and integrated approach to pastoral development.

2.9 Conclusions

Environment and livestock production systems are said to have multidimensional interactions and challenges because livestock production systems were affected by environmental change and at the same time they were contributors to the phenomenon. Livestock sector response to the challenges of environmental change requires formulation of appropriate adaptation and mitigation options. The projected trend of population growth indicates that livestock population will increase tremendously over the next few years and may create conducive conditions for further increase in greenhouse gas emissions. It is also important to study future effect of livestock on environment based on different technological adaptation options and scenarios that were suitable to smallholders. Genetic improvement programs should search for livestock breeds that are resistant to harsh environments that could allow for selection within and between breed/species that are suited to particular environmental conditions. Livestock feed and forage research should also seek for programs that can reduce gas emissions, adapt to harsh environments and also be highly productive per unit of animal product.

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CHAPTER 3: RESEARCH METHODOLOGY

3.1 Aims and objectives

3.1.1 The aim

The aim of this study was to determine the magnitude and intensity of livestock, soil, water, land, climate, crop and human interactions in the central Ethiopian highlands, with emphasis on the Ada district by using methodology that integrated socio-economic data and biological information with reference to secondary data.

3.1.2 The objectives

The objectives of this study were:

1. To assess the effect of change in land management on carbon storage and the contribution of livestock to carbon storage.
2. To examine the impact of livestock on natural resources and the environment.
3. To assess the effects of the change in traditional agricultural practices, expansion of factories, slaughter houses, greenhouses and flower farms on water and soil quality.
4. To evaluate the effect of climate change on livestock production under small-scale agriculture.
5. To recommend options for mitigation and adaptation to environmental changes.

3.2 Research design

The research design was non-experimental and did not involve the manipulation of the situation, circumstances or experiences of the interviewees. The design was comparative research that compared two or more groups on one or more variables, such as the effect of agricultural land use management, tillage type, etc. on carbon storage in the soil. This research also applied a longitudinal design that examined variables such as the performance exhibited by groups over time, for example the measurement of the impact of carbon inputs into soil over time. Purposive sampling was often used to measure the effect of agricultural, industrial effluent and human interferences on the environment by measuring nutrient contents at sources in the soil, water and manure. These biological data were complemented by key socio-economic survey by interviewing individual households and discussions with focus groups from sampling sites. Secondary data were also reviewed to measure soil degradation and run-off attributed to livestock.

3.2.1 Hypotheses

Null hypothesis

The interrelationships of livestock, soil, water, land, climate, crop, and humans under mixed crop and livestock production systems are detrimental to small-scale farming in central Ethiopian highlands.

Alternative hypothesis

The interrelationships of livestock, soil, water, land, climate, crop and humans under mixed crop and livestock production systems are beneficial to small-scale farming in central Ethiopian highlands.

3.2 The study area

The study area was Adaa district (Woreda) which is situated in high potential livestock-crop production systems (Amare, 1980; MoA, 2000). Administratively it is one of the 12 districts in East Shoa zone in Oromia regional state of Ethiopia. It is located about 45 km southeast of Addis Ababa the capital city, and is very close to the other major urban centers **(Figure 3.1).** The district covers 1750 km^2 surface area and the average altitude is about 1500 meters to over 2000 meters above sea level**.** The total agricultural population of the district is about 300,000 people (Bekele Soboka, 2010 personal communication). There are 36 Peasant Associations (the lowest administrative unit) of which 27 are in rural areas and 9 are in urban areas. There are two major agro-climatic zones: (a). The mountain zone located ≥ 2000 m above sea level, covering 150 km^2 (9%) of the district, and (b). The highland zone located at 1500-2000 m above sea level, covering 1600 km^2 (91%) of the district (IPMS, 2004).

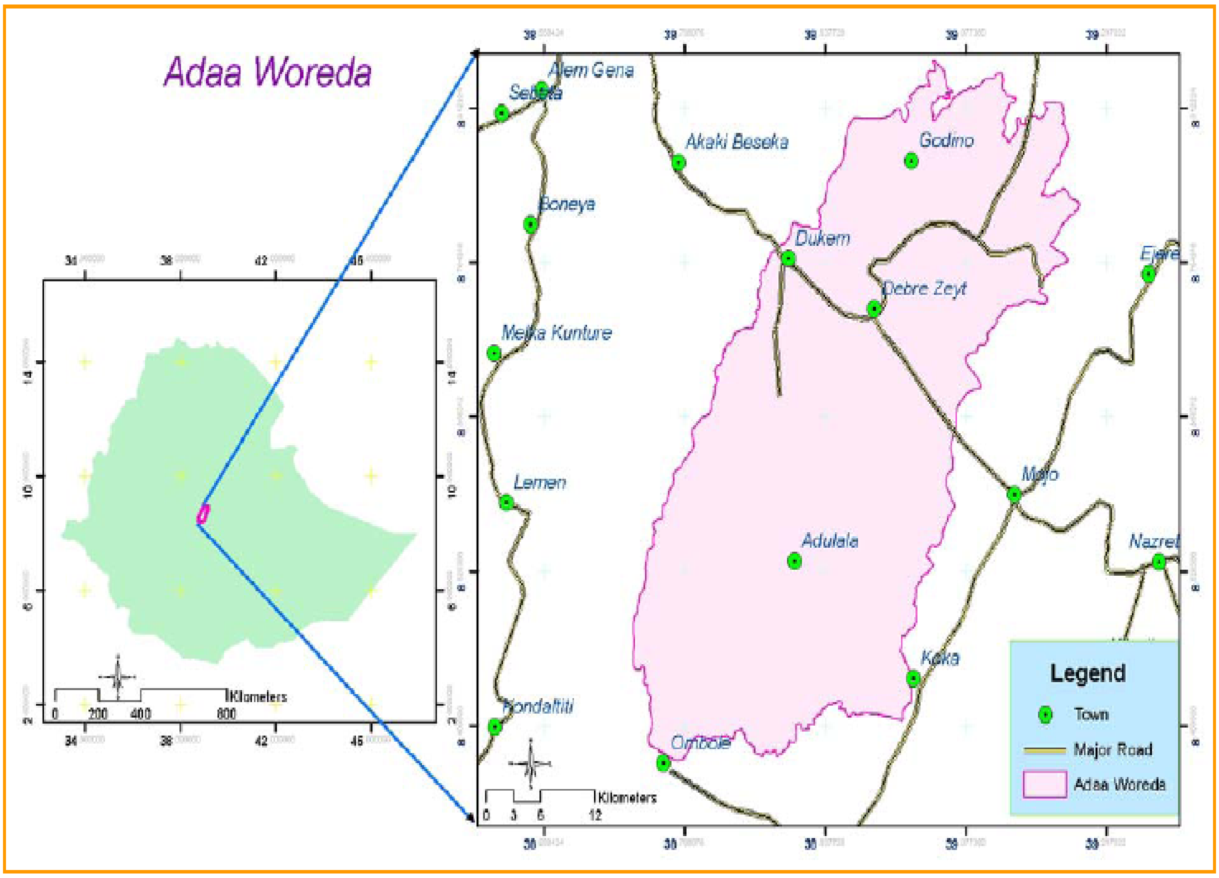

Figure 3.1: Location of the study area in Adaa district/Woreda

There are two cropping seasons in the area: the *Belg* or short rain season which occurs from March to April, and the *Meher* or the main rain season which occurs from June to September. The average rainfall from 1953 to 2003 which was recorded by ILRI and Ethiopian Institute of Agricultural Research (EIAR) was 839 mm (Kahsay, 2004). The average minimum and maximum temperatures for 27 years ranged from 7.90^{o}C to 28.0^{o}C, respectively, and the mean annual temperature for the same period was 18.5^{o}C. Dominant soil types in the area were vertisols, characterized by high water-holding capacity during heavy rain, and difficult to till. Farm management practices in the cereal-growing area included rotating grain crops with pulses for soil fertility and pest management. Livestock was an integral part of crop production which provided draught power for tillage, threshing and transportation of agricultural produce to the market.

3.4 Materials and methods

3.4.1 Materials

3.4.1.1 Material used for socio-economic survey

The sampling tool that was used in the socio-economic survey was an open-ended and semi-structured questionnaire that helped to capture the historical trend and current environmental condition and agricultural practices. A checklist was used for focus group discussion**.**

3.4.1.2 Material used for biological and physical data

Soil sampling was done using a sampling tube, an auger, a spade, labeled plastic buckets and labeled plastic sample bags. Soil sampling was done by taking four subsamples at 0-15 cm and 15 to 30 cm depths from each identified site within 50 m radius to form a pooled sample. The pooled subsamples from each site were placed in clean and labeled plastic buckets. The pooled subsamples in the plastic buckets were then spread on clean sheets of paper for air drying. The dry subsamples were then transferred to labeled sample bags and delivered to the laboratory for analysis.

Sampling of manure was done according to Zhang (2001) by scooping from four random spots on different heights (0 m, 0.5 m, 1 m, 1.5 m and 2 m) and on top of the manure heap to a depth of about 30 cm to make pooled subsamples at each height. Manure sampling was done by collecting samples from manure heaps aged from 0 to 3 years. Subsamples of 0.25 kg at each height were weighed and pooled to form a sample of each specific height and stored in labeled plastic bags of 1 kg each. The manure subsamples were kept in cooler boxes with ice cubes before transportation to the laboratory and then stored in a deep-freezer before analysis for N, P and K. Other data were also recorded based on the uses of the manure heaps such as for sale and or household fuel.

Water sampling was done by collecting factory effluents, ground water, swampy, and river water. Prior to sampling labeled 1L polyethylene bottles were cleaned by incubating them with 10% (v/v) nitric acid (Analytical, Merck) for 48 hours in a hot water bath and then washing and rinsing them with distilled and de-ionized water. They were also thoroughly rinsed with clean water at the sampling sites before sampling.

3.4.2 Methods

In order to simplify the study it was essential to divide the methodology into five sections: (1) The socio-economic survey using semi-structured interviews to capture information about community perceptions on climate change, constraints and possible solutions, about changes in land use, livestock, crop, water, natural resource, nutrient cycling (manure and crop residues) and their management; (2) The biological and physical data to complement the socio-economic findings; (3) The methods of data analysis; (4) The projected effects of the future climate change on livestock using different climate change scenarios; and (5) The adaptation options to climate change through literature review to intensify livestock production to meet the growing demand for animal protein.

3.4.2.1 Socio-economic survey and sample size

The district was divided into five zones, and from each zone two villages were randomly selected by the subject matter specialists in the District Agricultural and Rural Development Office. Eleven farmers were purposively selected from each village to represent different degrees of wealth, level of dependence on natural resources in pursuing their livelihoods, and the length of time they had lived in the study area. A total of 110 farmers were involved in the socio-economic study. The study was divided into two parts: (a) Individual household interviews, and (b) Group interviews, where selected individuals from the villages explained their local environment.

3.4.2.2 Biological study

This section dealt with the chemical analysis of soil, water and manure.

3.4.2.2.1 Soil tests

Soil tests were based on land management, crop history (such as crop-rotation), tillage type and organic matter addition into the soil. Samples were taken from the depths of 0-15 cm and 15-30 cm in tilled fields and in no-till fields. Soil testing focused on soil organic matter, macronutrients (P, N and exchangeable bases), soil pH, CEC and heavy metals. Soil organic carbon content was determined using the procedure described by Walkely and Black (1934). Total N content was determined using Kjeldahl method (AOAC, 2000), and CEC was determined using the Ammonia distillation method (Chapman, 1965). Particle size analysis was carried out using Bouyoucos method (Bouyoucos, 1951). All the micro-nutrients were determined by DTPA extract method through Atomic Absorption Spectrometer (Tadesse *et al.,* 1991). Soil pH was determined using a pH meter with a soil/water ratio of 1: 2.5. Available P was extracted according to Olsen *et al.* (1954). Exchangeable bases such as Ca were measured using 1N ammonium acetate per unit of meq/100 g of soil (Tadesse *et al.,* 1991).

3.4.2.2.2 Water sampling and site selection

Sample sites for water physico-chemical analysis were selected along water bodies and effluent flow courses based on the potential exposure to pollution by human and livestock waste disposal. Generally, the pollution sources were categorized in two as point and non-point pollution sources. Point sources involved the discharge of substances from factories, sewage systems and flower farms as it was easier to identify and monitor. Sample sites under this category were Zukuala Steel Rolling Factory, Oxford Plastic Package Factory, East African Detergent Factory and Wedecha River. The rest of the sample sites were classified as non-point sources as they were poorly defined and their sources of pollution were scattered over a large area. The major pollutants for non-point sources were agricultural run-offs from animal waste and farms.

Water sampling for physico-chemical analysis: Sampling was done from May to mid-June 2009. This period was strategically selected to represent the dry season before the on-set of rain. The critical water shortage for livestock was during the dry season when livestock trekked long distances in search of water. During the rainy season livestock drank water from run-offs, temporary stagnant water, roofs and roadsides. In the wet season, livestock drank water near the homesteads and around the grazing areas. Therefore, the appropriate time to study the interrelation between water and livestock in terms of use, depletion, and pollution, was during the dry season.

The samples were collected directly from the factory outlets and from different sampling locations along rivers, lakes, swamps, ponds and ground water which was used for livestock drinking once during the study period. Six subsamples from each point were taken and then pooled and mixed thoroughly before the analysis. One litre of water from each pooled sample was taken and used for all chemical analyses.

Since the water flowing from rivers and the dam were less than 3 meters deep grab samples were taken at livestock watering points, and for lakes six grabs of composite water samples were taken at livestock drinking points at about 500 meters radius. Sampling in ponds was done at livestock entry points. Ground water samples were collected after the pump had been running for 15 minutes. All samples were transported to the Debrezeit Research Centre within 2 hours of collection. All the procedures for water sampling were done as described by Tadesse *et al.* (1991) in water analysis manual.

Physico-chemical water data: In this study a detailed waste water characterization was performed for selected parameters. Total N, P, K, Ca, Mg, Cl, CO_3, H_2CO_3, dissolved solids (TDS), conductivity and pH of were measured as described by Tadesse *et al.* (1991) in the water analysis manual.

3.4.2.3 Chemical analysis of manure

Total N was determined using the micro Kjeldahl digestion, distillation and titration method (Tadesse *et al.,* 1991). Fresh manure samples weighing 0.5 g were used for the analysis. Total P and K were determined by dry ash method as described by Tadesse *et al.* (1991). Organic C was analyzed using Walkley-Black method. The DM content was obtained by oven drying subsamples at 105°C for 24 hrs. C:N ratio was computed by dividing the amount of C by that of N. Calculations were done on dry matter basis.

3.4.2.4 Analysis of field and laboratory data

Data obtained from the socio-economic survey, the biological and physical samples were analyzed statistically using SPSS version 17.0.1 (2008). Descriptive statistics: means, frequencies, percentages and cross tabulation were used to determine relationships between variables. Analysis of variance and multiple mean comparisons were computed for nutrient composition in the soil, water and manure data.

3.4.2.5 Climate change assessment

3.4.2.5.1 Climate change trends based on meteorological data

Sixty years of meteorological data was obtained from the Ethiopian National Meteorological Service Agency (NMSA) weather stations based in the study area. The meteorological data obtained were temperature (°C), rainfall (mm) for 365.25 days, wind speed (m/s), sunshine (hr) and relative humidity (%). The meteorological data of several decades were compared. The weather data reported here were based on information from Debrezeit Air Force weather station located in the study area. The long-term (1951-2009) data were used for rainfall, temperature and relative humidity, while the last three decades of data for sunshine hours and last two decades data of wind speed were used.

3.4.2.5.2 Crop suitability analysis for climate change

Crop suitability analysis uses FAO EcoCrop database of environmental requirements of a long list of plant species (White *et al.,* 2001). It is used to identify possible crops to grow in particular environments. DIVA-GIS implemented EcoCrop (Hijmans *et al.,* 2005) to predict the adaptation of crops over geographical areas that used to estimate crop yield and residue potential for future livestock feed. Currently, only temperature and precipitation data were used to make this prediction.

To be able to determine the suitability of a certain crop in a growing season, the following temperature parameters were used:

KTMP: Absolute temperature that will kill a plant,

TMIN: Minimum average temperature at which a plant grows,

TOPMN: Minimum average temperature at which a plant will grow optimally,

TOPMX: Maximum average temperature at which a plant will grow optimally, and

TMAX: Maximum average temperature at which a plant will cease to grow.

To be able to determine the suitability of a particular crop during the rainfall in an area the following rainfall parameters were used:

Rmin: Minimum rainfall in millimetres during the growing season,

Ropmin: Optimal minimum rainfall in millimetres during the growing season,

Ropmax: Optimal maximum rainfall in millimetres during the growing season, and

Rmax: Maximum rainfall in millimetres during the growing season.

EcoCrop module could run the rainfall and temperature parameters separately or both at the same time (the boxes to tick are in the predict table). In the case where rainfall and temperature were run together, the minimum values of the two parameters in each growing season were used to compute the suitability. To run the module, a species was selected in the tab or searched for by using the options in the filter and clicking on it. Temperature and rainfall parameters from the EcoCrop database in the parameters tab were inspected and changed as desired. In this case, temperature and rainfall were predicted from three climate change models (CGM2, HaDCM3 and PCM) for 2050 and 2100 (Deressa and Hassan, 2010). Teff and wheat were the selected crop types that were run using DIV-GIS. The two crops were selected for their relevance for their residues for livestock feed in central Ethiopian highlands (Alemayehu, 2005).

3.4.2.5.3 Identification of technological options for livestock production intensification

Literature was reviewed for the adaptation of alternative livestock related technology options to mitigate climate change.

3.4.2.6 Expected outcomes

Expected outcomes from this study would provide information for decision-making to improve sustainable livestock and environment development in four priority areas: (1) Application of industrial and agricultural practices for sustainable natural resource conservation and potential positive implications for livestock and human health; (2) Intensification of livestock development with potential implications for local and national sustainability; (3) Changes in land uses to match socio-economic and climate change, increasing human and livestock populations, and/or increasing resource uses with implications for sustainability; and (4) Suggestions for desirable and practical adaptation options and/or policies to effectively handle impacts of climate and socio-economic changes, and to ensure sustainable livestock development.

CHAPTER 4:
LAND MANAGEMENT PRACTICES AND THE ROLE OF LIVESTOCK IN CARBON STORAGE UNDER MIXED CROP-LIVESTOCK PRODUCTION SYSTEMS

4.1 Introduction

Soil carbon storage is defined as *"the process of transferring carbon dioxide from the atmosphere into the soil through crop residues and other organic solids, and in a form that is not immediately reemitted"*. This transfer or "storage" of carbon helps to off-set emissions from fossil fuel combustion and other carbon-emitting activities, while enhancing soil quality and long term agronomic productivity (Sundermeier *et al.,* 2005). The depletion of soil carbon is accentuated by soil degradation and exacerbated by land misuse and soil mismanagement (Lal, 2004). Thus, the adoption of restorative land management practices can reduce the rate of enrichment of atmospheric CO_2 while having a positive impact on food security, agro-industries, water quality and the environment. There is a positive relation between soil organic carbon in the top soil and crop yield (Lal, 2006). Thus, carbon storage is a win-win approach for improved environmental quality and increased agricultural production.

Under mixed crop and livestock production systems in Ethiopia, crop production is the major cash income earner (IPMS, 2004), while livestock production plays an important role as a source of draught power for crop production, organic fertilizer, a living bank; and household income and food (Hadera, 2001). Although livestock production is associated with environmental degradation and wholesale devastation of rangelands and irreversible desertification (FAO, 2006), there is ample evidence to show that livestock production contributes positively to carbon balance in the soil. The positive aspects of livestock production contribution to carbon storage is when farmers use animal power for farm operations such as ploughing, disking, ridging, weeding, threshing and transporting agricultural inputs and outputs; with zero carbon operations, compared with mechanized agriculture (de Hann *et al.,* 1998). The addition of animal manure and livestock waste into the soil is an alternative management option as carbon input for soil carbon storage (FAO, 2001; Lal, 2002; Lal, 2004).

However, due to socio-economic factors traditional practices such as leaving crop residues in the field after harvest have declined (Kahsay, 2004). Instead, crop residues are used for animal feed, house construction, fire wood and as a source of income (FAO, 2001). Crop residues are cut near ground level leaving nothing to turn back to the soil (Kahsay, 2004), and whatever stubble is left on the ground is extensively grazed and trampled, so that only bare ground remains, which exposes the soil to wind and water erosion. This negative crop residue management has contributed to the depletion of soil organic carbon and results in poor soil quality (Lal, 2004).

Animal manure is among the recyclable resources that are used to increase soil organic carbon. However, due to lack of firewood in the highlands to meet the fuel demand, farmers use animal manure for household fuel needs for cooking and heating (Tesfaye *et al.,* 2004). According to Tesfaye *et al.* (2004) the sale of animal manure in the highlands contributes about 25% of the total income from livestock production. Under the current manure management system in smallholder mixed agriculture, no animal waste is returned to the soil except urine. This has a serious impediment in soil carbon storage.

In general, permanent removal of crop residues and the usage of animal manure for household fuel and sales lower the content of soil organic carbon (FAO, 2001). Long term trials have shown that carbon losses due to human interventions can be reversed through improved land management practices which enhance carbon storage in the soil (Rosenberg *et al., 1999;* Lal, 2006). Therefore, it is important to study the impact of different land management practices under mixed crop-livestock production systems on carbon storage as well as the contribution of livestock production in carbon storage under different land management systems.

Previous research studies on carbon storage investigated natural resource management, forestry and soil perspective (Lal, 2004; Lemma *et al.,* 2007), whereas the current study investigated the role of livestock production, crop residue, land use, soil texture, tillage and manure management in carbon storage. Thus, the current study investigated whether different local land management systems increased soil carbon in mixed crop-livestock production systems in central Ethiopian highlands or not. It also investigated the contribution of livestock production in carbon storage and environmental quality.

The investigation was based on soil samples collected in 2009, as well as land, livestock and crop management history of each sample site obtained through interviews with farmers. The soil types in the study area were predominantly vertisols. The effects of land management practices (degraded, fenced, different soil tillage practices, crop history, different organic matter additions) contrasted with the soil management systems that have never been under cultivation for many years. Therefore, the purpose of this study was to quantify soil organic carbon in different land and agricultural management practices.

4. 2 Materials and methods

4.2.1 The study area

The study was conducted in central Ethiopian Highlands that represent a homeland for 90% of highland farmers. In the highlands, the main agricultural activity is smallholder mixed farming systems dominated by crop and livestock production (Constable, 1984). The highland area is further subdivided into three zones based on the development potential and resource base (Amare*,* 1980*)*, as: (a) the high potential cereal/livestock (HP/CL), (b) the low potential cereal/livestock (LP/CL), and (c) the high potential perennial crop/livestock (HP/PL) areas. Ecologically, the current study area falls under the high potential livestock-crop production system (IPMS, 2004), which is located southeast of Addis Ababa at longitude 38^{o} 51' 43.63'' to 39^{o} 04' 58.59'' E and latitude 8^{o}46'16.20'' to 8^{o} 59' 16.38'' N, on the western margin of the great East African Rift Valley (**Figure 3.1**). The altitude of the area ranges from 1500 m to ≥ 2000 m above sea level**.** Two major agro-climatic zones were identified in the area (IPMS, 2004): (a) mountain zone ≥ 2000 m above sea level, which covers 150 km^2 or 9% of the area, and (b) highland zone at 1500 to ≤ 2000 m above sea level, which covers over 1600 km^2 or 91% of the area.

The agro-ecology of the study area is best suited for diverse agricultural production systems. The area is known for its excellent quality Teff grain, which is an important staple food grain in Ethiopia that is used for making bread (Enjera). Wheat is the next abundant crop followed by pulses especially chickpeas which grow in the bottomlands and flood basins. Most farmers grow chickpeas in rotation with cereals, while livestock production is an integral and important part of the agricultural production systems.

4.2.2 Study methods

The study was designed to quantify soil organic carbon in different agricultural and livestock management systems. For data collection, the study combined the sampling of soil, water and effluent for laboratory analyses; and socio-economic survey by interviewing 110 farmers. The laboratory data was complemented by land management histories and the existing land management practices. Sample sites of alternative soil and crop management were selected purposely in consultation with farmers, experts and secondary data. The selected sites were stratified according to land management type to capture variation in farm practices. The selected sample sites had 12 characteristics and were further subdivided into soil texture types, tillage types, land management types and types of organic matter addition. Sample sites were described based on WOCAT (2012) categorization system for conservation measures and land use management, as shown below:

Site 1: Enclosed and resting land. This site had been undisturbed and never ploughed for ≥ 30 years. The land was covered with grass and shrubs. Therefore, the site was chosen as the benchmark for the assessment of the other sites.

Site 2: This site was a commercial farm with integrated vegetable, poultry and dairy production, where farmyard manure was used for seven years. The land was cultivated continuously without rest and farm operations were done with heavy machinery.

Site 3: This site had experienced crop rotations of cereals and pulses, following a pattern of Teff-chickpeas-wheat-chickpeas for three consecutive years. Crop rotation is considered one of agricultural management practices that recycle nutrients in the soil (Lal, 2006). This site was classified as an organic and chemical fertilization site (WOCAT, 2012)

Site 4: This site was under minimum tillage for six years. The land was ploughed once and then herbicides were applied during or just before seeding of cereals (Teff and wheat). The site was categorized as soil surface treatment according to WOCAT (2012).

Site 5: This site was a smallholder backyard manure application plot closer to the homestead. It was marked as organic matter addition site with manure (WOCAT, 2012).

Site 6: This site was a field where compost was applied for four years. The compost was made of household waste, ashes, leaf litter, crop, and vegetable residues. The site represented organic matter addition into the soil with compost fertilizer (WOCAT, 2012).

Site 7: This site was a field where crop residues were well managed. The crop residues were left in the field and ploughed into the soil at the end of the cropping season. The site represented a category of agronomic soil management by retaining crop residues.

Site 8: This site was a field which was continuously cultivated deeply with heavy machinery. Inorganic fertilizers were used at a rate of 200 kg/ha for DAP and 100 kg/ha for Urea on cereals every year. The site was classified as soil sub-surface treatment with deep tillage according to WOCAT (2012).

Site 9: This site was overgrazed, degraded and eroded land. The site was categorized as degraded land.

Site 10: This site was degraded and adjacent to **Site 9.** It was fenced off for more than 15 years. Fencing is a well-known practice for replenishing nutrients in the soil. The site was classified as degraded and enclosed.

Site 11: This was an animal waste disposal site for over 40 years without any crops being grown. The site had a gentle slope and the soil was highly eroded. Animal waste such as bones, blood and offal was dumped into a pit which was already too full. Bushes grew on the edges of the pit. The site was categorized as organic matter addition site through waste disposal.

Site 12: This site was swamp land where runoff from mountains leached away nutrients from the farms and deposited them in the swamp. The runoff from urban areas also accumulated there during the rainy season. The swamp dried up during the dry season between March and June and the swamp was then used for grazing. The site was classified as swampy land.

The sample sites were further subdivided into soil texture and tillage types. The soil textures were subdivided into four classes based on the AOAC (2000) as loam, sandy loam, silt loam and clay loam.

The tillage types were classified as described by Abiye and Ferew (1993) as follows: (a) deep cultivation tillage that uses mechanized tractors with disc ploughs at a depth ≥ 20 cm, (b) minimum cultivation tillage that involves the removal of weeds first by using herbicides followed by ploughing only once at a depth of 8 to 10 cm before sowing, (c) shallow cultivation tillage that uses traditional ox-drawn ploughs at a depth of 15 to 20 cm, and (d) no cultivation or no tillage where the land is never ploughed for a long period.

4.2.3 Soil sampling and analysis

In June 2009, soil samples were taken from the 12 sites described above. Site number 1 was identified as the benchmark because it was undisturbed by human interventions for a long period of time. Before sampling, forest litter, grass and any other material on the ground were removed. Soil samples were collected purposely to describe the different land management practices and conservation measures such as degradation, area enclosure, crop history, tillage type, level of fertilization, residues left in the field and compost or manure application. Samples were taken at the depths of 0 to 15 cm and at 15 to 30 cm with four subsamples at each composite site. Thus, a composite sample was made from four pooled subsamples. The four subsamples at each site were pooled for homogeneity and stored in a plastic bag and transported to Debrezeit Research Centre for soil analysis in the Soil Laboratory within two hours of collection.

Soil moisture analysis was done by oven drying for 24 hours at 105^{o}C. Air dried soil was ground with mortar and pestle and sieved through a 2 mm sieve. Soil organic carbon content was determined by using the procedure described by Walkely and Black (1934). Total N content was determined using Kjeldahl method (AOAC, 2000), and CEC was determined by the ammonia distillation method (Chapman, 1965). Particle size analysis was done using Bouyoucos method (Bouyoucos, 1951). Soil **bulk** density was estimated by using the Adams equation (Adams, 1973) as shown below:

$$BD = \frac{100}{(\%OM/0.224)+(100-\%OM/MBD}$$

Where; BD = bulk density,

OM = organic matter, and

MBD = mineral bulk density.

A typical value of 1.64 was used for MBD (Mann, 1986).

The soil samples were weighed after drying. The amount of carbon per unit area was calculated using the method described by Pearson *et al.* (2005) as shown in the formula:
C (t/ha) = [soil bulk density (g/cm^3) x soil depth (cm) x %C] x 100

N.B: Carbon content is expressed as a decimal fraction, e.g. 2.2%C is expressed as 0.022. Crop, soil and land management practices for each site were described based on detailed interviews with farmers, key informant information and literature review.

4.2.4 Statistical analysis

Detail statistical analysis was done using SPSS version 17.0.1(SPSS, 2008).

4. 3 Results and discussion

4.3.1 Soil organic carbon content in the study sites

According to FAO (2001), when the above ground woody biomass increases it can act as a permanent carbon sink. Woody vegetation with deep and extensive root systems can capture nutrients that are not accessible by crops and make them available through litter fall and fixing of nitrogen by leguminous plants (Lal, 2002). Therefore, **Site 1** which was chosen as a reference site in order to compare it with other alternative soil conservation and land management practices had 1.27% SOC at 0 to15 cm and 0.31% at 15 to 30 cm depth.

Site 2 which was a commercial farm had SOC of 1.65% at 0 to 15 cm depth and 0.73% at 15 to 30 cm depth. At both depths, the organic carbon content was higher than the benchmark site because of the addition of farmyard manure. It was reported by FAO (2001) that farmyard manure is usually of higher quality than dung and droppings left in the fields by grazing animals.

Site 3 which practiced crop rotation of cereals with pulses for over three years (usually Teff-chickpea-wheat-chickpea operated in rotations), had 2.13% SOC at 0 to 15 cm depth and 1.02% at 15 to 30 cm depth. Crop rotation is considered as one of the agricultural management practices that add nutrients to the soil (Lal, 2004). The organic carbon content was better than the previous two sites, may be due to biological nitrogen fixation (Beyene, 1988) which might have enhanced microbial activity that contributed to higher soil organic carbon.

Site 4 which practiced minimum tillage for six years had SOC content of 1.06% and 0.34% at depths of 0 to 15 cm and 15 to 30 cm, respectively. The carbon content at both depths was slightly comparable to the benchmark site. Wood and Edwards (1992) argued that the impact to soil organic carbon became significant when both conservation tillage and crop-rotation were practiced. Hernanz *et al.* (2009) studied three tillage practices namely; conventional tillage, minimum tillage and no tillage, and found that the average soil organic carbon content was 14% higher in no tillage than in minimum tillage and conventional tillage. They also reported that in no tillage the soil organic carbon content increased in the top layer but declined systematically in the bottom layers. That showed that minimum tillage can be an alternative carbon storage mechanism under mixed crop livestock production system.

Site 5 which practiced smallholder farmyard manure application at the homestead had SOC contents of 1.85% and 1.33% at 0 to 15 cm and at 15 to 30 cm depth, respectively. The most limiting factor in the usage of farmyard manure was lack of transport to spread the manure, in addition to lack of animals in some smallholder mixed farms, which limited its use around homesteads more than on more remote fields (FAO, 2001). The smallholder backyard manure application showed higher carbon content at a depth of 15 to 30 cm than the commercial farm. This could be attributed to the depth of tillage. Smallholder farmers used oxen power for shallow tillage which could not go beyond the depth of 20 cm (Abiye and Ferew, 1993); which made less carbon losses compared to commercial farms that practiced deep tillage.

Site 6 which practiced the use of compost manure for 6 years had 1.12% SOC content at 0 to 15 cm and 1.17% at 15 to 30 cm depth, respectively, which was much higher than the other sites except site 5. The compost was made out of household waste, ashes, leaf litter, crop and vegetable residues to increase soil fertility. Very often the compost was added to manure piles and transported to the fields where it was spread out. Although the use of such alternative organic matter increased overall biomass it was rarely sufficient to cover entire fields (FAO, 2001). The rationale for the increased soil organic carbon content at 15 to 30 cm depth was that composting improved the decomposition rate (FAO, 2001).

Site 7 which practiced crop residue management by leaving crop residues in the fields to decay into humus had SOC contents of 0.07% and 0.80% at 0 to 15 and 15 to 30 cm depths, respectively. The upper layer carbon content was lower because at the time of sampling, the field had been ploughed and thus some of the soil carbon might have been already lost to the air. The carbon content at 15 to 30 cm was much higher, which might indicate that crop residue management could be an alternative agricultural practice for carbon storage under smallholder agricultural activities. However, in mixed crop-livestock production systems, crop residues are removed after harvest either as fodder, construction material, fuel or litter for composting, and in most cases crop residues are sold at the local market to generate additional income (Kahsay, 2004)

Site 8 which was continuously cultivated and fertilized with inorganic fertilizers had SOC content of 0.07% at 0 to 15 cm and 0.25% at 15 to 30 cm depth. The soil organic carbon content was the lowest in both layers compared with other sites. The major reason for low SOC in both layers could be deep tillage with tractor-mounted disc ploughs. This showed that unless organic carbon input is added to the soil, deep tillage is the major contributor to losses of SOC to the atmosphere. In this site fertilizer was applied at a rate of 200 kg DAP and 100 kg Urea per hectare for cereals every year after deep tractor ploughing. Post and Kwon (2000) reported losses of SOC of as much as 50% in surface soil (20 cm) in soils that were deeply cultivated for over 30 years.

Site 9 which represented degraded land had SOC content of 2.21% at 0 to 15 cm and 2.16% at 15 to 30 cm depth. The land was degraded due to overgrazing and erosion. FAO (2001) categorized land degradation into three groups namely: physical degradation, which is mainly driven by climatic factors such as floods and droughts that cause soil erosion (by wind and water); chemical degradation, which is generally in the form of salinity (mainly on irrigated lands); and biological degradation, which is mainly a result of the oxidation of the topsoil organic matter. The high SOC content of this site was attributed to the fact that degradation was limited to the surface layer. **Site 9** might not have been subjected to the all three types of degradation, but it might have been exposed to physical degradation that was limited to the upper layer.

Site 10 which was degraded land adjacent to **Site 9**, but closed to animal and human access for more than 15 years; had SOC contents of 2.32% and 1.23% for 0 to 15 cm and 15 to 30 cm depths, respectively. The area represented a well-known practice of replenishing nutrients in the soil. Fenced areas are usually on hillsides that cannot be used for cultivation but are protected from animal and human access for certain periods of time until the land is covered with vegetation (FAO, 2001). The beneficiaries are only allowed to cut and carry forages from the areas and feed their animals elsewhere. Fenced areas gained organic carbon through dead litter on the soil and nitrogen fixation; which reduced nutrient losses caused by wind and water (FAO, 2001). Consequently, the SOC content was higher on this site than the other alternative land management systems.

Site 11 which was a dump for the local slaughter house waste (bones, horns, offal and blood); and was highly eroded. The SOC content was 3.9% at 0 to15 cm depth and 1.15% at 15 to 30 cm depths. The higher SOC content at 0 to15 cm depth was probably due to the organic matter concentration from animal waste.

Site12 which was a swamp where runoff from mountains and nutrients from farmlands were deposited; had SOC content of 0.27% at 0 to 15 cm and 3.23% at 15 to 30 cm depth. Urban flood water also accumulated in the swamp during the rainy season. The swamp dried up during the dry season from March to June and was used for grazing. This indicated that soil organic carbon and other elements sank down and infiltrated the ground water, which could have impacted on the health of human and livestock drinking the water. The high SOC at 15 to 30 cm also showed that there was excess nutrient deposition on one end and loss at the other end. Swampy areas, urban dairies and abattoirs were net importers of nutrients from rural farms because there was excess deposition of nutrients in their systems (Yoseph *et al.,* 1999; FAO, 2001).

4.3.2 Soil texture, cation exchange capacity and carbon to nitrogen ratio

The soil texture of the study sites were categorized into four as: loam, sandy loam, silt loam and clay loam. According to Berhanu (1985) the vertisols in Ethiopia have CEC of 35 to 70 meq/100 g soil, while Beyene (1988) reported a range of 22 to 42 meq/100 g soil. **Table 4.1** shows that CEC values ranged from 22 to 59 meq/100 g from 0 to 30 cm soil depth, which was in agreement with the ranges reported by other workers. Beyene (1988) reported C:N ratio of about 11:18. In this study C:N ratio was 0.47:17. The lowest C:N value was found in **Site 8** which was continuously and deeply cultivated for many years. This indicated that deep tillage could be one of the most important factors in soil organic matter depletion under mixed crop-livestock production systems in the Ethiopian highlands.

Table 4.1: Soil organic carbon, soil texture and carbon to nitrogen ratio

	Site type	SOC (%)		Soil texture		CEC meq/100g		C:N Ratio	
		0-15 cm	15-30 cm	0-15 cm	15-30 cm	0-15 Cm	15-30 cm	0-15 cm	15-30 cm
1	Debrezeit Research Centre - undisturbed	1.27	0.31	Silt loam	Silt loam	53.2	53.2	6.88	2.17
2	Genesis farm - Commercial	1.65	0.73	Loam	Sandy loam	29.2	30.2	9.35	5.01
3	Crop rotation - small hold	2.13	1.02	Loam	Loam	52.8	58.8	17.25	7.46
4	Minimum tillage - Small hold	1.06	0.34	Loam	Clay loam	54.8	52.8	7.50	2.66
5	Farmyard manure small hold	1.85	1.33	Sandy loam	Clay loam	53.4	54.8	9.63	8.25
6	Compost used - small hold	1.12	1.17	Loam	Loam	58.8	58.8	6.31	6.82
7	Crop residues – small hold	0.07	0.80	Clay loam	Clay loam	58.8	58.8	0.74	8.48
8	Mechanized cultivation – small hold	0.07	0.25	Loam	Loam	48.6	44.6	0.47	2.48
9	Degraded communal grazing land	2.21	2.16	Sandy loam	Sandy loam	32.4	37.2	6.38	7.55
10	Fenced, cut and carry allowed	2.32	1.23	Sandy loam	Loam	22.8	27.8	10.70	6.24
11	Animal waste disposal site - slaughter house	3.90	1.15	Sandy loam	Sandy loam	52.8	41.2	8.57	3.03
12	Swamp land	0.21	2.48	Silt loam	Silt loam	46.6	44.6	1.17	11.51

4.3.3 Effects of soil texture on soil organic carbon content and the role of livestock on soil structure and fertility

Asnakew (1988) reported that vertisols contained more than 40% clay in the surface horizon and close to 75% in the middle part of the profiles. The sand fraction was lower than 20% and was found at the bottom and surface of the ploughed horizons. Srivastava *et al.* (1993) also found that the clay content of the study area was 50% in the surface layer. These findings showed that the clay content at 0 to 15 and 15 to 30 cm depths was between 20 and 30%, and the sand content at both ranged from 20 to 50%. Haque *et al.* (1993) noted that chemical properties of vertisols in the current study area showed low OM content and total N, while Yimer (1992) reported that at 0 to 25 cm depth soil organic carbon content was 1.86% or at moderate level. In the present study the average SOC content for all soil textures was 1.4% at 0 to 15 cm and 1.0% at 15 to 30 cm depth **(Table 4.2)**, which was below the values reported by Yimer (1992). The possible reason for low SOC in the present study was the effect of anthropogenic factors such continuous ploughing, removal of crop residues, and change in traditional practices such as the use of manure for fuel energy.

Table 4.2: Mean soil organic carbon for soil textures at 0-15 and 15-30 cm

Soil texture	Sample size	SOC at 0-15 cm	SOC at 15-30 cm
Clay loam	4	0.79 ± 0.70	0.66 ± 0.76
Loam	6	1.31 ± 0.74	0.81± 0.44
Sandy loam	3	2.81 ± 0.95	1.51 ± 0.56
Silt loam	2	0.74 ± 0.75	1.40 ± 1.53
Total	**15**	**1.40 ± 1.03**	**0.99 ± 0.73**

The soil textures of the study area were: clay loam (27%), loam (40%), sandy-loam (20%) and silt loam (13%). There was a significant difference in SOC content among the soil textures at 0 to 15 cm soil depth, but there was no significant difference at 15 to 30 cm depth as shown in **Table 4.3**.

Table 4.3: ANOVA of soil organic carbon for soil textures at 15 and 30 cm

Variables		**Sum of squares**	**df**	**Mean square**	**F**	**Sig.**
SOC * soil texture at 0- 15 cm	Between groups	8.39	3	2.80	4.719	0.02
SOC at 15-30cm * soil texture	Between groups	1.79	3	0.60	1.156	0.37

Post and Kwon (2000) reported that the amount, decomposability and placement of carbon inputs above and below ground differ between ecosystems and with land uses. Therefore, the significant differences in SOC content at 0 to 15 cm depth could be due to the effect of land management practices such as the addition of farmyard manure, compost, crop residues and the use of conservation tillage. The non-significance of SOC at 15 to 30 cm depth could be due to a reduced amount of disturbance in land management practices. Agricultural practices such as the traditional ox-drawn plough has less capacity to mix carbon inputs to below 20 cm soil (Abiye and Ferew, 1993) and therefore, the natural carbon deposited in the soil remains intact.

The mean SOC content at 15 to 30 cm depth showed that sandy loam textured soils had 1.51 ± 0.56% and silt loam had 1.40 ± 1.53% **(Table 4.2)**. Both textures maintained better carbon contents than loam and clay loam which had 0.81 ± 0.44% and 0.66 ± 0.76%, respectively. These results showed that sandy loam and silt loam exhibited almost twice the content of carbon than loam and clay loam. This implied that porosity had an effect on carbon storage. The carbon mass calculated for the four soil classes was 68.4 t/ha, 63.7 t/ha, 38.1 t/ha and 31.3 t/ha for sandy loam, silt loam, loam and clay loam, respectively. FAO (2001) noted that an addition of 1 ton of soil carbon pool may increase wheat yield by 20 to 40 kg/ha on degraded crop lands. Based on this calculation sandy loam soil could produce 484 to 742.1 kg more wheat per hectare than clay loam.

To be able to translate the impact of carbon storage on livestock it is important to mention about the use of crop residues as animal feed under smallholder mixed agriculture systems. And to estimate the amount of crop residues produced from increased yield, extrapolation of grain to straw ratio was applied. Grain and straw yield ratio for wheat was reported at 1:1.8 (Kahsay, 2004). That meant the more the grains yield the higher the straw production for livestock feed.

There is a relationship between SOC content and soil texture (Christensen, 1996), which showed that the highest concentration of SOC content was associated with less than 5 µm mineral particles, and as a result clay soils showed greater accumulation and rapid losses of SOC than silt. Most of the areas in the current study sites were vertisols (IPMS, 2004; Kahsay, 2004) with 50% clay content (Srivastava *et al.,* 1993). Low SOC content and poor response to chemical fertilization, were some of the characteristics of vertisols (Haque *et al.,* 1993). Thus under traditional soil management practices vertisols produce low yields. However, there was ample proof to show that vertisols were capable of producing much more food and feed than they were producing at that time, provided that they were adequately and properly managed (Mesfin and Jutiz, 1993). Abate *et al.* (1993) reported that with proper drainage of vertisols using broad bed maker, cereal grain yield increased by 106% and that of straw increased by 78% compared to traditional drainage systems. The effect of improved drainage on fertilizer use efficiency of cereal was investigated by Abate *et al.* (1993) who found that grain and straw yields were increased by 30%. These authors noted that different crops and soil husbandry practices increased grain and straw yields. For example, sequential cropping increased yields by 60%; mixed cropping of legumes and cereals raised yields by 40%; row intercropping of forage legumes with cereals boosted yields by 30%; and forage grass and legumes mixed cropping improved yields by 40%. All these findings confirmed a high biomass production of both grain and straw. These results showed that through proper soil and agronomic management practices it is possible to increase SOC content and land productivity.

The contribution of livestock in managing vertisols can be reflected when draught animals are used to draw broad bed maker for better aeration, nutrient uptake and improved yields (Mesfin and Jutiz, 1993). Improved vertisol management will not only give higher yields because of soil content improvement, but will also reduce soil erosion (Abate *et al.,* 1993). Under smallholder mixed agriculture, livestock has a role in generating power for the improvement of soil structure and fertility.

It should also be noted that N is the most limiting nutrient in vertisols. The use of forage and grain legumes enhances N fixation which leads to increased productivity of grain and straw (Beyene, 1988). Hence, animal feed production can be integrated with soil structure and fertility improvement. Animal manure and other animal wastes increase SOC content and total N that contributed to increased grain and straw yield to meet the nutrient demand by livestock for better milk and meat production.

4.3.4 Effect of tillage on SOC content and the contribution of livestock in carbon storage

The depth of ploughing has a significant impact on carbon storage in the soil, where organic matter and roots are mechanically mixed on the top layer. Sundermeier *et al.* (2005) reported that sub soiling at 35.6 cm depth lost more carbon than ploughing at 20.3 cm depth, while strip tillage lost even less, and no-tillage lost the least carbon. In 40-year experimentation in Ohio State University, Sundermeier *et al.* (2005) found that continuous no-tillage nearly doubled the organic matter content in the top 5 cm, while ploughing reduced it by a third. In another study conducted in Brazil, Barreto *et al.* (2009) reported that soils under natural vegetation and conservation tillage systems generally had higher aggregation indices and total organic carbon stocks in the surface layer than soils under conventional management. In that study, no-tillage had its effect on carbon stabilization between the natural ecosystem and conventional tillage.

Hernanz *et al.* (2009) studied different tillage practices: conventional tillage, minimum tillage and no-tillage; under experimentation which combined the rotation of cereals with pulses for twenty years. They found that the average SOC content was 14% higher in no-tillage than in minimum tillage and conventional tillage. They also reported that in no-tillage, stocked SOC content increased in the top layer but declined systematically in the bottom layer.

In the current study, tillage types were categorized as: deep cultivation, minimum cultivation, shallow cultivation, and no cultivation (uncultivated). Deep cultivation is that type of tillage which uses a mechanized tractor with a disc/moldboard plough at a depth of more than 20 cm (Abiye and Ferew, 1993). Minimum cultivation is that tillage where weeds are removed first by using herbicides and followed by ploughing only once at the depth of 8 to 10 cm followed by sowing. Shallow cultivation is that type of tillage that uses traditional oxen-drawn ploughs and tillage is at a depth of 15 to 20 cm (Abiye and Ferew, 1993). No cultivation or uncultivated is where an area has never been ploughed for a long period e.g. 30 years. The ANOVA showed that there was a significant difference in carbon content between tillage types at both 0 to 15 cm and 15 to 30 cm depths. The level of significance was higher at 15 cm than at 30 cm.

The mean SOC contents at 0 to 15 cm depth were 0.86%, 1.06%, 1.18%, and 1.98% for deep cultivation, minimum cultivation, shallow cultivation, and no cultivation, respectively **(Table 4.4).** The SOC content at 30 cm depth for different soil tillage types also followed a similar trend as shown in **Table 4.4**. The results suggested that tillage was the most important parameter in terms of carbon storage than soil texture. Land that has never been cultivated had a storage of 87.55 tons/ha carbon compared to 40.34 t/ha for deeply cultivated land. Shallow cultivated land under traditional farming methods using oxen-drawn ploughs had carbon storage capacity of 54.28 t/ha, compared to deeply cultivated land, a difference of 14 t/ha carbon stored. These results were in agreement with the findings by Wood and Edwards (1992), which showed that after 10 years of experimentation and comparing conventional moldboard plough tillage with conservation tillage, the latter had increased surface carbon and nitrogen to 67% and 66%; respectively.

Table 4.4: SOC content and tillage types at 15 and 30 cm (Mean ± SD)

Tillage type	Soil carbon % at 15 cm	Soil carbon % at 30 cm
Deep cultivation	0.86 ± 1.06	0.49 ± 0.34
Minimum cultivation	1.06	0.34
Shallow cultivation	1.18 ± 0.76	0.88 ± 0.61
Uncultivated	1.98 ± 1.37	1.47 ± 0.87
Total	**1.40 ± 1.03**	**0.99 ± 0.73**

Assuming 14 tons of carbon per hectare was saved by shallow cultivation as compared to deep ploughing and by multiplying that with 10 million hectares that were ploughed by draught power in Ethiopia (MoFED, 2011), the amount of carbon saved by using shallow ox-driven ploughs was estimated at 402 million tons of carbon per year. In double cropping, the amount of carbon saved from emissions was twice as much. In addition to the carbon saving, shallow tillage fostered carbon-free non-fuel consuming farm operations. And for not burning a litre of gasoline, it saved 0.64 kg of carbon (FAO, 2004). Emissions into the atmosphere by agricultural mechanization from processing to tractor operations in the field were significantly higher. For example, a wheat farm required about 50 tractor hours per hectare to complete farming operations (FAO, 2004). Thus, total fuel consumed by wheat production per hectare was estimated to be about 250 litres of gasoline or 160 kg of carbon emissions per hectare (FAO, 2004). When it is multiplied by 10 million (the area of land cultivated by smallholders using animal draught power in Ethiopia) it amplified the total amount of carbon saved in Ethiopia to 1.6 million tons of carbon per year.

One of the anticipated benefits for smallholders in the carbon credit scheme was financial gain that could be achieved from carbon trading. Carbon credits create a market for reducing greenhouse emissions by giving a monetary value to the cost of polluting the air. Nordhaus (2008) suggested that based on the social cost of carbon emissions, an optimal price of carbon is around US$ 30 per ton and will need to increase with inflation. Thus, the carbon saved by shallow tillage contributed to carbon trade of 140 million tons per year. In addition to the 1.6 million tons of carbon saved from not burning gasoline for mechanization, it totals carbon trade to 141.6 million tons per year. At the current levels of carbon saving by smallholder farm operations, a tax of US$ 30 per ton of carbon would generate US$ 4.25 billion of revenue per year. And for 15 million smallholder farmers in

Ethiopia (MoFED, 2008), their per capita share from carbon trading would be US$ 283.33 per annum because of shallow tillage.

Mechanization breaks soil structure and contributes to wind and water erosion, too. Mechanization also releases carbon monoxide, carbon dioxide and other greenhouse gases from fuel combustion (Soon *et al.,* 2006). Hence, shallow ploughing with animal power is a fairly positive farm operation from an environmental point of view because it uses an energy source which is renewable and reasonably non-polluting. In addition, animal power serves as a means of transport which is also relatively pollution free unlike gasoline that releases carbon dioxide into the air. This indicated that livestock plays a crucial role in carbon storage and in reducing global warming. However, it is controversial to continue under traditional farming given the current increase in human population which calls for increased food production

4.3.5 The influence of different land uses and the contribution of livestock to SOC content

There are many factors and processes that determine the direction and rate of change in SOC content when different land use management practices were applied (Post and Kwon, 2000). The land uses in the current study area were categorized as: crop production, grazing, wetland (swamp land) with seasonal grazing and fallow land without cultivation. The ANOVA at 95% confidence interval showed that there was a significant difference in SOC content among the land uses as shown on **Tables 4.5 and 4.6.**

Table 4.5: SOC content for land use categories at 15 and 30 cm (Mean ±SD)

Land use category	Soil carbon % at 15 cm	Soil carbon % at 30 cm
Crop production	1.10 ± 0.73	0.75 ± 0.55
Grazing	2.27 ± 0.08	1.70 ± 0.66
Wetland/swamp with seasonal grazing	0.21 ± 0	2.48 ± 0
Fallow land (undisturbed)	2.59 ± 1.86	0.73 ± 0.59
Total	**1.40 ± 1.30**	**0.99 ± 0.73**

The mean SOC for land use categories were 2.6%, 2.27%, 1.10% and 0.21% for fallow land (undisturbed), grazing, cropping production and wetland (swamp land), respectively, at 15 cm depth **(Table 4.5)**. The carbon content was acceptable and agreed with the findings of the other workers (Post and Kwon, 2000), except for the lower carbon content of wetland (swamp land). The reason for lower carbon content in wetlands at 15 cm depth was due to the leaching of carbon and nitrogen to the bottom layer (FAO, 1999). This was also supported by the evidence that higher carbon content was observed at 30 cm depth for wetlands. Grazing land in both degraded and fenced off was second and was attributed to the addition of dung and urine to the soil (Hoffmann and Gerling, 2001) as well as the ability of livestock to move organic matter from place to place and mix it with soil particles (FAO, 2001). The other plausible reason could be that grazing land might have been degraded physically but not chemically. This suggestion however, needs further investigation on the type of degradation exhibited on this particular grazing land.

Table 4.6: ANOVA of SOC under different land uses at 0-15 and 15-30 cm

Variables		Sum of squares	F	Mean square	F	Sig.
Soil carbon * land use category at 0-15 cm	Between groups	6.61	3	2.20	2.91	0.08
	Within groups	8.32	11	0.76		
	Total	14.93	14			
Soil carbon * land use category at 15-30 cm	Between groups	3.94	3	1.31	4.09	0.04
	Within group	3.54	11	0.32		
	Total	**7.48**	**14**			

The current results validated the importance of livestock production in SOC storage under two different grazing sites: degraded and fenced off land. However, this was in disagreement with many other reports (de Hann *et al.,* 1998; FAO, 1998) which reported that livestock production was responsible for both physical and chemical degradation of the soil. Therefore, the current findings call for further investigations on the positive and negative roles of livestock in degradation and the carbon sink.

4.3.6 Agricultural carbon input addition and carbon storage in the soil

According to FAO (2001), the addition of organic matter to the soil was through the use of farmyard manure, green manure, legumes in rotations, vermi-compost, and fallows in rotations; all these increased SOC and agricultural yields. But when inorganic fertilizer was used alone to increase nutrient supply it resulted in the decline of carbon in the soil in all systems, or only small increases, when used with no-tillage (FAO, 2001). No-tillage increased SOC, although the accumulation was greatest when organic matter was added to the soil. At the local level the best land management practices have to be chosen based on the existing farming systems. Thus, for example, the application rate of organic matter to the soil has to correspond with quantities that were available to local farmers. However, at the farm level, important trade-offs may not occur to prevent the adoption of the best strategies for carbon storage. Crop residues may be required for livestock feed or fuel rather than be returned to the fields, or may be sold for cash in difficult times. Thus, many socio-economic factors interact to determine which scenario or combination of scenarios has to be implemented in each growing season (FAO, 2000).

Some of the results predicted that soil carbon can be restored to pre-cultivation levels, and in certain circumstances to above the original levels. The true “indigenous soil carbon level” was often difficult to establish in systems where agricultural activities have remained the same for several centuries or millennia in some parts of Ethiopia (Hoben, 1995). To achieve quantities of soil carbon in excess of the “original level” implies that the agricultural system had greater productivity than the indigenous system, assuming that carbon was not imported into the indigenous system. The scenarios that predicted the highest carbon storage rate were often associated with the introduction of trees to the system. The inputs of carbon from trees were more resistant to decomposition than those from herbaceous crops, and caused marked increases in the level of soil carbon (Falloon and Smith, 2002).

In the current study, nine carbon input methods were examined and compared as shown on **Table 4.7**. The major carbon input sources were from animal waste disposal. They represented city abattoir wastes where animal offal and other wastes were dumped in the fields. The SOC content was 3.9% at 0 to 15 cm and 1.15% at 15 to 30 cm depth. The low SOC content at 15 to 30 cm showed that the movement of nutrients downwards was slow in this case.

Table 4.7: Carbon yield from carbon inputs added into the soil

Source of carbon input *(a)*	**Carbon % at 15 cm** *(b)*	**Years of carbon Input** *(c)*	**Current carbon yield (t/ha)** *(d)*	**Carbon yield per year (g/m^2/y)** *(e)*
Animal waste	3.9	50	50.86	101.72
Crop rotation	2.13	3	29.53	984.33
Farm manure	1.75	7	24.59	351. 29
Fenced area	1.20	10	17.20	172.00
Compost	1.12	4	16.11	402.75
Minimum tillage	1.06	6	15.28	254.67
Deep tillage	0.79	3	11.50	383.33
Crop residues	0.07	3	1.08	36.00
Benchmark Site(undisturbed)	1.27	30	18.17	60.57

NB. d = C (t/ha) = [soil bulk density (g/cm^3) x soil depth (cm) x %C] x 100; and *e* = d/c (Pearson *et al.,* 2005)

The urban dairies and abattoirs were net importers of nutrients from rural farming systems as there was excess deposition of nutrients in the system (Yoseph *et al.,* 1999). Therefore, it is worth mentioning that an alternative mechanism has to be designed to balance nutrient flow from one system to the other in order to create equilibrium. The second best practice which contributed to soil carbon input was crop rotation of cereals with pulses which was practiced for a period of over three years. The crop rotation usually involved Teff, chickpea and wheat. SOC content for crop rotation was 2.13% at 0 to 15 cm and 1.02% at 15 to 30 cm depth. The carbon yield was 984.33 g/m^2/year at 0 to 15 cm soil depth.

The third most important management practice for carbon input was the use of farmyard manure. The application of farmyard manure has long been treated as a valuable source of organic matter to enhance soil fertility (FAO, 2001). Jenkinson *et al.* (1990) reported that for the same carbon input, carbon storage is higher with manure application than with plant residues. The reason for this difference was that manure helps the formation and stabilization of soil macro-aggregates (Whalen and Chang, 2002) and particulate organic matter (Kapkiyai *et al.,* 1999). Manure is also more resistant to microbial decomposition than plant residues (FAO, 2001). The SOC content of farmyard manure plot was 1.75% at 0 to 15 cm and 1.03% at 15 to 30 cm depth.

The area that was fenced off from grazing had a carbon yield of 172 g/m^2/years as shown on **Table 4.7**. White *et al.* (1976) (cited in Post and Kwon, 2000) found a lower value of 21 g C $m^{-2}y^{-1}$ and Burke *et al.* (1995) reported an accumulation of 3.1 g C $m^{-2}y^{-1}$ in the short grass steppe on unimproved and abandoned crop fields. These results suggested that longer periods were required for more pronounced increases in total SOC under conditions of low productivity. The fenced off area had the highest soil carbon levels than crop land that was subjected to conservation tillage (Franzluebbers *et al.,* 2000). Reeder and Schuman (2002) also found that there was an accumulation of litter in an un-grazed semi-arid system and the soil carbon level was higher than in the grazed lands. Deep tillage was a carbon negative practice (Hernanz *et al.,* 2009). Even with the addition of crop residues, deep tillage produced negative carbon storage as shown in **Table 4.7 and Figure 4.1**. And in general, for all the top three carbon input practices, livestock products and by-products play a greater role in carbon storage.

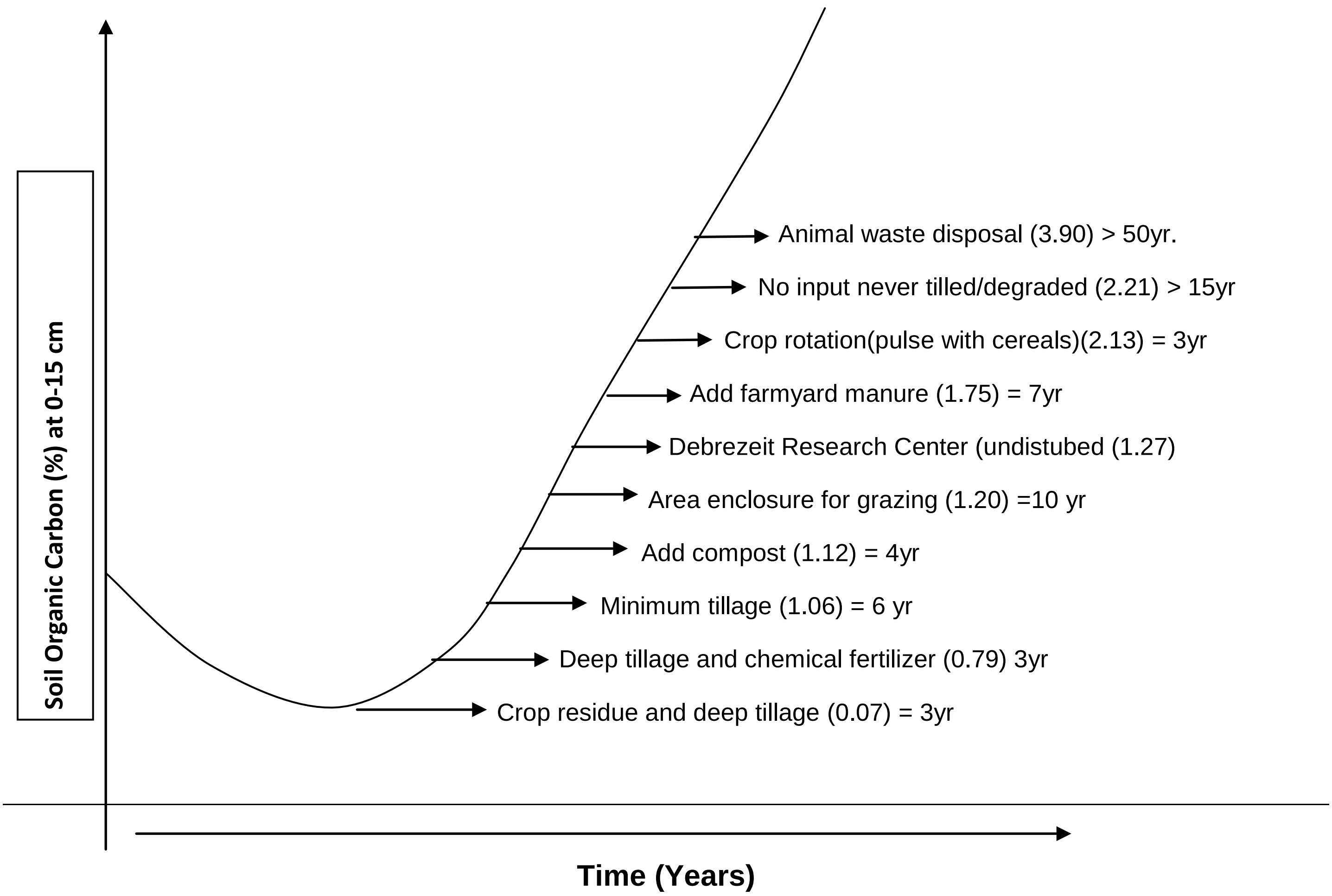

Figure 4.1: Carbon sources and addition time

4.4 Conclusions and recommendations

The use of draught animal power for ploughing, threshing and transportation saved tremendous carbon emissions compared to mechanized agriculture. And in addition to carbon release to the atmosphere, mechanized farm operations broke down the soil structure thus contributing to wind and water erosion. Mechanization also released carbon monoxide, carbon dioxide and other greenhouse gases from fuel combustion. Hence, draught power ploughing was a positive farm operation when considered from an environmental point of view.

When comparing the different land uses; grazing was found to have the highest SOC, followed by fallow land (undisturbed) ecology. Both the degraded and fenced off grazing areas had high SOC because of the ability of livestock to add dung and urine to the soil and their capability of moving organic materials from place to place. As a result, it is possible to argue that the upper surface of grazing land might be degraded physically but not chemically. The results of this study showed that although livestock was blamed for degrading the soil structure and vegetation this was compensated by adding organic carbon into the soil through dung and urine.

In contrasting the different carbon inputs added into the soil, it was found that animal waste and farmyard manure had the highest contribution. This implied that for most of carbon inputs livestock products and by-products had a greater place in the carbon sink. Therefore, livestock production could be considered as one of the major agricultural production systems in soil carbon storage. Similarly, these production systems also play an important role in maintaining the eco-system balance through nutrient recycling.

Livestock play a crucial role in the drainage of water from vertisol soils by pulling broad bed makers for better aeration and nutrient uptake by plants. As a result, SOC improvement contributed to increase in the yield of grain and straw that led to increased milk and meat production. It was found that different crop and soil management practices increased grain and straw yield under vertisols. Particular combination of leguminous forages with cereal crops improved soil carbon and yield by 40%, while row intercropping of forage legumes with cereals boosted the yield by 30% and forage grass and legumes mixed cropping improved yield by 40%. Therefore, livestock and livestock feedstuff were key players in improving the soil texture and SOC.

CHAPTER 5:
USE AND MANAGEMENT OF MANURE BY SMALLHOLDER FARMERS AND THEIR EFFECT ON THE ENVIRONMENT

5.1 Introduction

In 2010 the livestock population of Ethiopia was estimated at about 53.4 million cattle, 48.3 million shoats, 8.1 million equines and 1.1 million camels (FAOSTATA, 2012). The average annual livestock population growth rate was 1.3%, 1.0% and 0.9% for cattle, sheep and goats, respectively (Getachew and Gashaw, 2001). That meant the production and availability of animal feeds has to increase at a higher rate than the livestock population growth rate (Alemayehu, 2005). In general, human and livestock populations in Ethiopia have grown at an alarming rate (Ahmed *et al.,* 2003). As a result, there has been a lot of pressure on natural resources. Livestock overgrazed pastures and crop residues became major sources of animal feed in the highlands. Forests and bushes were cleared for crop production, grazing and fire wood (Alemu, 2002). Likewise, animal manure became a significant source of fuel energy for households (Tesfaye *et al.,* 2004).

Manure production, collection and storage vary with management practices (Tesfaye *et al.,* 2004). In the case of indoor management practices, manure was collected through a drainage gutter in a pit in liquid form. For outdoor management practices, manure was collected from the kraals at night and at day time from the fields while animals were grazing (Harris and Yusuf, 2001). The use of manure varies with management practices as well. For indoor management practices, biogas is used for fuel energy and slurry for fertilization. However, the transport of slurry from homesteads to the fields is the major challenge limiting wider use (Brandjes *et al.,* 1996). In outdoor management practices, the loss of manure in the field was higher due to droppings not being picked and urine being absorbed into the soil.

Manure has become a major energy source as cooking fuel in the rural areas (Asres, 2003). The amount of manure stored has become an indicator of wealth for rural households. Manure has also become one of the major contributors to household income, of about 25% of household income for poor farmers (Tesfaye *et al.,* 2004). The use of manure for cooking fuel and sales has a serious environmental impact as far as soil nutrient recycling (Fernandez-Rivera *et al.,* 1995) and greenhouse gas emissions are concerned (FAO, 2006).

Although livestock production has several advantages in smallholder agriculture, it is also the largest global source of methane emissions representing 20 to 25% of all sources of methane (IPCC, 2001). In addition, it is the greatest generator of N_2O which contributes to global warming (IPCC, 2001; Kurihara *et al.,* 2002). Livestock mismanagement is also blamed for soil degradation through overgrazing, trampling and compaction (de Hann *et al.,* 1998).

Animal manure is more efficiently utilized in crop production than commercial fertilizer because a larger fraction of nutrients from manure is absorbed by crops (Brandjes *et al.,* 1996; FAO, 2006). However, manure storage in the open causes volatilization of ammonia due to the high temperature and the leaching of NO_3, P and K (Jackson and Mtengeti, 2005). Surface spreading of manure without mixing it with soil during periods of high precipitation on fallow lands, may also lead to volatilization, leaching and surface runoff (Brandjes *et al.,* 1996).

Although manure remains an important organic source of fertilizer and fuel energy, its impact on the environment has never been given adequate research it deserves, particularly under mixed crop and livestock production systems (Tesfaye *et al.,* 2004). One of the purposes of this study was therefore, to document the effect of manure storage and age of storage on the loss of nutrients under mixed crop and livestock production systems of smallholder farming.

Research on the use and management of manure in the highlands was done by Tesfaye *et al.* (2004) who described the types of manure storage, means of transport and the level of use as fertilizer. However, their report did not describe the effect of different types of manure storage and management practices on the loss of nutrients and the pollution level under smallholder farming systems. Getente (2003) reported the effect of manure and N fertilizer on the establishment, herbage yield and seed production of perennial grasses in a research station in the Ethiopian highlands. The National Meteorological Service Agency in Ethiopia-NMSA (2001) and Asres (2003) undertook a greenhouse gas emissions inventory for all sources in Ethiopia based on the guideline from IPCC (1996), including level of pollution level. However, they did not report about the impact of different manure management practices on the local environment and did not scale it down to household level.

The current study attempted to assess the different manure management practices and their benefits to smallholder farmers. The study addressed:

- the trends of livestock holdings in the past three decades,
- the use, handling and storage of manure and their benefits,
- loss of nutrients from different types of manure storage and the age, and
- household gas emission levels due to the mismanagement of manure.

Information on these research issues was captured through household interviews, focus group discussions and manure sampling for chemical analysis.

5.2 The objectives

The objectives were:

- To document the production and storage of manure under smallholder farming.
- To assess the handling and use of manure under smallholder farming and the limitations to the use of manure as organic fertilizer.
- To estimate household loss of nutrients and gas emissions due to the mismanagement of manure.

5.3 Materials and methods

5.3.1 The study area

The study area was Adaa district which has a high potential for mixed livestock and crop production systems. It is one of the 12 districts in East Shoa zone in Oromia regional state of Ethiopia. It is located southeast of Addis Ababa at 38^{o}51' 43.63'' to 39^{o}04' 58.59'' E and 8^{o}46' 16.20'' to 8^{o}59' 16.38'' N, on the western margin of the Great East African Rift Valley. The altitude ranges from 1 500 m to ≥ 2 000 m above sea level. There are two major agro climatic zones: the mountain zone located ≥ 2 000 m and covers 150 km^2 (9%); and the highland zone that covers ≥ 1600 km^2 (91%) of the area. The average annual rainfall is 839 mm. Mean minimum temperature is 8^{o}C and mean maximum temperature is 28^{o}C. The mean temperature at the time of sampling was 18.5^{o}C. The dominant soil types were vertisols, which are fertile but poorly drained and difficult to work on (IPMS, 2004).

The district is best suited for diverse agricultural production systems, both for intensive and extensive agriculture. Teff (*Eragrostis teff*) and wheat are the most abundant crops that grow in the district in addition to pulses. Most farmers rotate chickpeas with cereals, and livestock production is an integral part of the agricultural production systems. Oxen are used as draught power for ploughing, threshing, while equines are used for threshing and transportation.

5. 3.2 Research design

The study used both biological and socio-economic approaches. The biological approach used target sampling to assess different losses of nutrients due to the type of manure storage and age, and their implications on the environment. The biological data were then validated by socio-economic data from interviews and group discussions with owners of the manure.

5.3.3 Socio-economic survey

The data used in this study were collected in a socio-economic survey which was undertaken in 2009. A total of 110 smallholder farmers were selected from representative villages and were interviewed. The data were analyzed using SPSS version 17.0.1 (2008). The information obtained from the survey included livestock ownership trends, manure collection methods, storage type, benefits and the limitations to the use of manure. Focus group discussions were also carried out with owners of manure that was sampled for laboratory analysis.

5.3.4 Biological study

Heaps of manure in different households were identified and classified according to their size, age and storage conditions; then sampled as described by Tadesse *et al.* (1991). A total of 25 pooled samples were collected. The storage conditions were classified as shaded, open and fresh (not in a heap) as shown in **Table 5.1**. Sampling of manure was done by scooping subsamples from four random spots on each manure heap at different heights i.e. 0 to 50 cm, 50 to 100 cm, 100 to 150 cm and ≥ 150 cm at the depth of about 30 cm (Zhang, *et al.,* 2001; Jackson and Mtengeti, 2005). The four subsamples from each representative height of the manure heap were pooled and a sample of approximately 1 kg was taken and stored in a plastic bag before chemical analysis. The pooled samples from each manure heap were air dried and ground to pass through a 2 mm screen ready for further analysis based on guidelines described by Tadesse *et al.* (1991).

Table 5.1: Manure storage condition, heap height and storage age

Storage condition	Heap height (m)	Storage age (yr)	Frequency	Feed management
Shaded	1 – 1.5	1 – 3	6	Indigenous animals fed on straw and supplements.
Shaded	1.5 – 2.0	> 3	4	As above
Open	0 – 0.5	0.5 – 1 r	1	As above
Open	0.5 – 1	0.5 – 1 r	9	As above
Open	1 – 1.5	0.5 – 1 r	2	As above
Fresh	0	0 r	3	As above

Key to storage conditions:

1. Shaded: means manure heap covered with grass, mud or plastered with manure itself.

2. Open: mean manure not covered or protected from sun and rain.

3. Fresh: means dung collected within 12 hours of dropping.

5.3.5 Chemical analysis of manure

Total N was determined using the micro Kjeldahl digestion, distillation and titration method as described by Tadesse *et al.* (1991). Total P and K were determined by dry ash method as described by Tadesse *et al.* (1991). Organic carbon was analyzed using Walkley and Black (1934) method as described by Tadesse *et al.* (1991). The DM content of the manure was obtained by oven drying the 25 pooled samples at 105°C for 24 hrs. The C:N ratio was computed by dividing the amount of C by that of N. Calculations were made on DM basis.

5.3.6 Statistical analysis and mathematical calculations

SPSS Version 17.0.1 (2008) was used for statistical analysis and interpretation of data from socio-economic and chemical analyses. Greenhouse gas emissions from manure were estimated using mathematical formulae described by the IPCC (1996) as follows:

Methane (CH_4):

Methane emissions per household were calculated for cattle, shoats (sheep and goats) and equines (horses, mules and donkeys) using the average number of animals in a household according to the inventory methodology described by IPCC (1996). Therefore,

ECH_4 (kg/yr)= fCH_4 (kg/head/yr) x P (average number of animals)

Where; *ECH_4 (g/year) = Emissions,*

f CH_4 (kg/head/year) = Emission factor, and

P = Average number of animals in each household

Nitrous oxide (N_2O):

The IPCC uses emission factors of cattle, shoats, equines and poultry to calculate N_2O emissions as follows:

N_2O = N x EF

Where; *N_2O = emissions from the animals (kg N/year),*

N = number of animals, and

EF = N_2O emission factor (kg N_2O-N per animal).

The emission factor (EF) is a function of the N excretion from the animal (IPCC, 1996) and the waste management system in the region (IPCC, 1996). The N_2O emission factors of shoats as well as equines were estimated by averaging them. The default values from the IPCC (1996) were used to calculate the EF.

C release: The amount of carbon released from burning manure per household was adapted from IPCC (1996) formula which was used to estimate carbon released from burning crop residues as follows:

C (kg/day) = Manure C fraction x manure DM fraction x total DM manure burnt/day

5.4 Results and discussion

5.4.1 Number of livestock per household

Cattle were the major sources of manure produced in the study area. Similar results were reported by Tesfaye *et al.* (2004) in the central highlands and Ferdu *et al.* (2009) in the northern highlands of Ethiopia. In addition, shoats, equines and poultry contributed to manure production (NMSA, 2001). To avert the risk of manure shortage, highland farmers owned various livestock species (Ferdu *et al.,* 2009). The livestock stocking trends for the last 35 years under different government administrations (eras or regimes) in Ethiopia are shown in **Table 5.2**. Generally, the average number of animals per household increased during the Derge era in the 1990s compared to the Haile Sellassie era in the 1970s; and then the number declined during the current era in the 2000s. However, the number of equines, indigenous oxen and crossbreeds of various species has increased during the current era as shown on **Table 5.2**. Ferdu *et al.* (2009) reported that the size of land owned and cultivated was a major factor that determined the number of animals owned except for poultry and shoats.

Generally, the political environment, access to technology, resource endowment, market and financial capability were the major factors that influence the type and number of livestock owned by households (Ferdu *et al.,* 2009). In the current study respondents said that the reason for the low number of livestock owned during the Haile Sellassie era was that most of the households were tenants of landlords with little individual assets at that time. The high number of animals per household during the Derge era was after the 1975 rural land reform. The 1975 rural land proclamation took away land from landlords and distributed it to the previous tenants including assets such as livestock under their control. Although the present average livestock ownership per household has declined steadily compared to the end of the Derge era, there has been an overall increase in livestock population for all households by 3% compared to the end of Haile Sellassie era.

Table 5.2: Average number of livestock per household under three governments

Species	**End of Haile Sellassie era (1974)**		**End of Derge era (1991)**		**Current era (2009)**	
	Indigenous	Improved	Indigenous	Improved	Indigenous	Improved
Cattle	6.5	0.03	8.4	0.06	8.1	0.19
Oxen	2.33	0.02	3.04	0.01	3.07	0.03
Shoats	6.3	0.0	7.5	0.0	4.3	0.0
Equine	1.3	0.0	1.9	0.0	2.1	0.0
Poultry	6.3	0.1	11.4	.00	7.6	0.15
Beehives	0.8	0.0	0.6	0.0	0.3	0.0

There were signs of an increase in crossbred cattle per household and a significant decrease in shoats. The shoats declined because they were more easily converted into cash to solve personal problems, feed shortages and disease epidemics. Ferdu *et al.*

(2009) found that in northern Ethiopia, when households faced an income deficit they responded mainly by reducing the number of small animals because they were relatively easy to convert into liquid cash and there was a readily available market. In the current study, the general cattle ownership had declined slightly, but oxen population had increased. The increase in the number of oxen and crossbred cattle, and the decrease in other livestock categories indicated that farmers were keeping livestock for specific purposes. Draught animals were kept for ploughing and transport and crossbreed animals were kept for the milk market. In a similar study conducted in northern Ethiopia under mixed agriculture, it was reported that with increasing income farmers preferred to own more oxen; and those who owned more oxen were found to be interested in owning pack animals as well (Ferdu *et al.,* 2009).

Change in crop intensification led to a change in the purpose of livestock keeping as well. Farmers started keeping certain animals for specific purposes unlike the traditional way of livestock keeping where animals were kept for prestige and insurance against risks by owning a diversity of livestock species (Williams *et al.,* 1995). The major drive for a change of attitude towards the purpose of keeping livestock was the scarcity of resources, mainly feed and water. Equine ownership has significantly increased due to lower off-take rate and the feeding habits of equines which have helped them to survive under harsh environments where feed resources were extremely scarce.

5.4.2 Manure production, uses and sales

Crossbred dairy cattle produced more manure per day (4 to 5 kg DM) than indigenous cattle (2 to 2.5 kg DM) (Fernandez-Rivera *et al.,* 1995). Based on the average of 8.1 indigenous cattle ownership, a household was expected to collect 16.2 to 20.3 kg of manure per day. However, in the current study households collected manure in the range of 2.1 and 2.8 tons per year or 6.6 kg per day per household in open grazing as shown in **Table 5.3**. Tesfaye *et al.* (2004) estimated the production of manure at 20 to 54 kg per day per household under indoor management in Holetta. This difference shows that there might have been losses during manure collection. A similar case was reported in sub-Saharan Africa where losses during manure collection and storage were less documented (Murwira *et al.,* 1995; Harris and Yusuf, 2001).

In the present study, out of the total manure collected per household, two thirds was used for household fuel energy supply and one third was sold to generate income. About 93% of the respondents collected manure for fuel energy supply and only 24% sold to generate income. The amount of manure sold per household dropped from 1 078 kg in 2006 to 618 kg in 2008 **(Table 5.3)**, but there was a slight increase in household annual income from the sale of manure due to price increase as shown in **Table 5.3**. Ninety percent of the cases of manure sales were operated by women. There were no significant differences in manure production, home use and the amount sold for the three years period.

Table 5.3: Amount of manure produced, used at home or sold

Year	**Production (Tons)**	**Home use (Tons)**	**Sold (Tons)**	**Income per year (Birr)**
2006	2.8 ± 3.7	1.7 ± 3.4	1.1 ± 1.5	325 ± 265
2007	2.4 ± 3.1	1.5 ± 2.8	0.9 ± 1.2	332 ± 204
2008	2.1 ± 3.0	1.5 ± 2.9	0.6 ± 0.9	340 ± 253

5.4.3 Methods of manure collection

Manure collection was the first step in the manure management process. When animals grazed crop residues, dung and urine were added to the soil resulting in subsequent increase in crop yields (Powell *et al.,* 1993). This practice saved power that could have been used to collect, transport and spread manure in the fields. In the current study, indigenous breeds were kept overnight in kraals near homesteads and grazed on crop residues and road sides during the day. Manure was collected from the homesteads and in the fields. In the fields, urine was not captured and the amount of dung collected was below production, because about one third of the manure produced was lost in the fields (Tesfaye *et al.,* 2004). In this study, 96% of the farmers said that 50 to 100% of their manure sources came from the homesteads from night droppings in the kraals. About 54% of respondents indicated that 25% of their manure sources were from field collections, which illustrated that more manure was lost in the fields as shown in **Table 5.4.**

All manure was collected by women and children. Homestead manure was collected early in the morning before animals went out to graze in the fields. Women did pan-caking and storage. The manure was usually collected in one place and pan-caking was done by mixing manure with straw and moulded into pancakes. The addition of straw made the pancake stronger, easier to mould, easier to store and easier to ignite (Tesfaye *et al.,* 2004). Poor farmers who did not own livestock had to collect dung from open fields. Livestock dung that was collected from the fields was for free. Manure heaps around homesteads was an indicator of wealth.

Table 5.4: Frequency of respondents and sources of manure in the study area

Manure source	Frequency of respondents			Total
	1 – 25% Source of income	**25 – 50% Source of income**	**50 – 100% Source of income**	
Homestead	1	2	96	99
Field collection	54	5	5	64
Purchase	1	0	0	1
Total	**56**	**7**	**101**	**164**

5.4.4 The process of storing manure and factors affecting storage

Manure was stored in two ways, i.e. before pan-caking while it was fresh and after pan-caking in the form of heaps. The heaps of pancakes were covered with a grass roof and/or sealed with wet dung to protect from rain, wind and sunshine. Women stored the pancakes near their main gates. In each heap, there were window-like openings for easy and frequent removal of pancakes for home use and for sale.

Each pancake weighed about 500 to 1200 g and was sold for US$ 0.02 to 0.03. Some farmers with about 4 livestock units (TLUs) who specialized in the manure business reported earnings of about US$17 per annum. In the rainy season, farmers stored manure in pits waiting to prepare pancakes during the dry season. Manure pancakes were not prepared during the rainy season to avoid loss of nutrients and the wetness of manure from rain.

Powell *et al.* (1993) and Tittonell *et al.* (2010) described the storage condition, age and the height of manure heaps; and how they affected the quality of manure. The majority (90%) of the respondents covered manure with grass roofs or sealed the grass roofs with wet dung. The age of manure heaps varied from 6 months to > 3 years. Wealthy farmers kept manure heaps for longer periods than poorer farmers. The better off farmers did not sell manure for income generation, so that they could accumulate it in bulk.

The manure heaps were usually dome shaped with conical narrow tips in order to avoid the infiltration from rainwater. The quality of manure was affected by environmental factors such as rain, humidity, insects and rodents (Brandjes *et al.,* 1996). Respondents in this study ranked the severity of the effects of these factors on manure quality as rain (32%), insects and rodents (31%) and humidity (30%). Rain made manure wet and difficult to burn. Wet manure produced a lot of smoke which affected human health. Poor manure storage favoured mould and fungi development, and became a hiding place for insects and rodents.

5.4.5 Manure uses and benefits

It was assumed that manure would be used for fertilizer, but the bulk of it was used for fuel energy. About 99% of the respondents used manure for cooking fuel **(Table 5.5).** The monthly average manure consumption was estimated at 165 kg per household, which was about 5.5 kg of manure from two cows per day **(Table 5.5)**.

Table 5.5: Household monthly energy usage and sources of energy

Purpose	Wood (m^3)	Electricity (w)	Kerosene (l)	Manure (kg)	Residues (leaves)	Candles (no.)	Charcoal (kg)
Lighting							
Respondents	-	17	85	1	-	1	-
Mean (± SE)	-	18.3±4.7	2.8±1.6	8	-	4	-
Cooking							
Respondents	85	3	32	100	19	-	17
Mean (± SE)	4.8 ±3.2	7.3±1.1	4.3±1.5	165±18	20	-	13.8±5.7

Another use of manure was for fertilization. The recommended amount of fertilizer in the current study area was 45 kg/ha N for Teff and wheat production (Bekele Soboka, personal communication). Based on the current N content of manure (1.40% DM) for a household to produce enough manure for a 2 ha land plot they had to produce 6 400 kg of manure per annum. To achieve that amount a household has to collect 18 kg manure per day, which is impossible to attain since the manure collection in the present study was 6.6 kg per day per household.

Manure was also used as a plastering material for wall painting, grain stores, manure sealing, flooring and bed decoration, threshing grounds and covers for Enjera baking plates. In these activities all nutrients were lost to non-crop production activities. When manure was burnt directly, most of the C and all of the N and S were lost (Tesfaye *et al.,* 2004). However, other nutrients like K and P were recycled in arable land through the spread of the ashes in the fields.

The current cattle ownership of 8.1 was closer to the requirement of meeting the amount of manure for fertilization. However, in **Table 5.3** it is shown that farmers in the study area were only able to collect one third of the manure produced, of which more than 80% was used for cooking fuel. Only 36% of respondents used manure as a fertilizer in their backyard land plots as shown in **Table 5.6**. The average household land covered with manure was only 0.30 ha or 18% of total land owned, and the remaining 81% of the farm land was fertilized with chemical fertilizers or without any fertilizers as shown in **Table 5.6**.

There was a significant difference (P<0.01) in yields among crop types in response to manure application. Vegetables produced higher yields with manure than chemical fertilizers. Cereals responded more to chemical fertilizers than manure, which could be attributed to the application rate of manure. However, for sustainable crop production, a combination of manure and chemical fertilizers would be the best option (Brandjes *et al.,* 1996) as shown in **Table 5.6**.

Table 5.6: Area coverage, amount of production and type of fertilization

Crop	Farmyard manure		Chemical fertilizer		No fertilizer used		Manure users
	Acreage (ha)	Yield (Qt)	Acreage (ha)	Yield (Qt)	Acreage (ha)	Yield (Qt)	%
Teff	0.52± 0.5	3.5±2.4	1.2±0.9	12.6±9.4	3.0	4.5	9
Wheat	0.4±0.2	4.5±2.1	0.8±0.6	11.5±9.1	-	-	2
Maize	0.8± 0.1	10.2± 4.4	1.0± 0.3	13.5± 2.5	1.0 ±.2	15.1± 4	17
Vegetables	0.25	23.00	0.25	16.75±7.46	0.25	4.0	1
Mean(±SE)	**0.30±0.5**	**5.20±5.39**	**0.95±0.8**	**12.25±11.2**	**0.41±0.43**	**5.69±4.42**	**-**

Respondents in the study area ranked the limitations to the use of manure as: inadequate production of dung, high labour cost of collection in the fields, bulkiness, high transport cost, and the risk of weed infestation when manure was spread in the fields **(Table 5.7)**. On top of the unavailability of manure, the above reasons were some of the factors that discouraged farmers from using manure as an organic fertilizer. There was also lack of awareness on the benefits of manure among farmers. The current findings were in agreement with the findings by Lekasi *et al.* (1998) in Kenya, Tesfaye *et al.* (2004) in Ethiopia and Jackson and Mtengeti (2005) in Tanzania who also reported about the limitations to the use of manure by smallholder farmers.

Table 5.7: Limitations to the use of manure for fertilization

	Rank (%)							
Limitations	1	2	3	4	5	6	7	**Total %**
Inadequate amount	13.2	4.7	2.2	1.7	0.2	0.0	0.0	22.2
Difficult to transport	2.2	3.0	6.0	5.5	1.7	0.0	0.0	18.5
High application rate	2.5	8.0	3.7	4.2	0.0	0.7	0.2	19.5
Weed infestation	0.5	0.7	0.7	3.0	10.0	1.0	0.0	16.0
High labour cost	3.7	5.7	6.2	1.7	2.0	0.5	0.0	20.0
Distant plots	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.2
Lack of awareness	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.6
Substitute firewood	1.2	0.7	0.0	0.5	0.2	0.2	0.0	3.0
Total								**100.0**

5.4.6 Nutrient losses due to poor manure management

Comparisons were made for N, P, K and OM based on different manure management systems such as manure heaps based on the following criteria: the type of cover, age and height of manure heaps. Covering of manure heaps reduced the loss of carbon, ammonia-N and greenhouse gases (Hansen *et al.,* 2006). On the contrary, in the current study manure heaps which were not covered had an average N content of 1.4 ± 0.3%, while covered manure heaps had 1.2 ± 0.7% N content. In general, N, P and K values were higher for manure stored in the open than those which were covered. The ANOVA showed significant differences ($P< 0.05$) between covered and open manure heaps for N, P and K. The difference was due to the fact that open manure heaps were those between the ages of 6 to 8 months, while covered manure heaps were over one year in storage. This indicated that the longer the storage period, the higher the nutrient loss through emissions, leaching, decomposition, and physical weathering (Tittonell *et al.,* 2010).

Long storage periods of manure slurry and high temperature increased C and N losses, depending on storage conditions (FAO, 2006). Harris and Yusuf (2001) reported N losses of up to 59% in Ghana during three months of storage of manure. A comparison of manure based on the storage age that is shown in **Table 5.8** indicated that with increasing age the nutrient depletion for N, P, K increased, particularly the N loss rate was higher than for the other two nutrients due to the volatile nature of N (Kulling *et al.,* 2003; Rotz, 2004).

In the current study the highest loss of N, P and K occurred in 2 to 3 year old manure at the rate of 84%, 19% and 42%; respectively. The ANOVA showed that at $P<0.05$, there was a significant difference in storage period of N and K, but there was no significant difference for P across different storage periods. The current findings are in agreement with the results obtained in Kenya (Tittonell *et al.,* 2010). N loss during (aerobic) composting varied from 20 to 80% (Lekasi *et al.,* 1998). These authors reported that losses were by far the highest for N, followed by K and P which agreed with the current findings **(Table 5.8)**. Therefore, storage of manure for more than two years has a serious environmental impact on ammonia-N, NO_3 and N_2O (Brandies *et al.,* 1996).

Storage period showed significant differences in chemical composition (Lupwayi *et al.,* 2000). The OM content was higher for fresh manure (76%) compared older manure at 6 to 12 months (36%). The difference of about 40% in OM between fresh manure and 6 to 12 months old manure could be attributed to weathering. The loss of OM and other nutrients increased with increasing age of manure as shown in **Table 5.8.**

The other factor that affected nutrient depletion was the height of the manure heaps. Petersen *et al.* (1998) reported that the loss of K, OM and N were much higher for manure stored in heaps than manure stored in a pit. In the current study most farmers (80%) stored manure in heaps while 2% of them used deep litter storage. Heap heights of up to 2 m were recorded in the study area. The ANOVA for manure height at $P<0.05$ showed no significant differences in chemical composition because of heap height. This could be due to the fact that the top of the heaps were well protected from weathering, whereas lower layers were enriched by nutrients leaching from the upper layers, which made the nutrient composition uniform across different heap heights, as shown in **Table 5.8**.

Table 5.8: Chemical composition of manure in shade storage, heap height and age

Composition	Manure shade		Storage age (yr)					Heap height (m)			
	Covered	Open	Fresh	0.5-1	1-2	2-3	>3	0-0.5	0.5 -1	1-1.5	1.5-2
%DM/kg	97.8±0.8	97.2	81.84±6	97.2±0.4	97.1±0.3	96	96.4±2	96.5	97.2	96.9	98
%OM/kg	36.3±10	36.6±11	76.2	36.6±11	32.1±7.6	31	45.0±2	55	50	49	33
%N/kg	1.2±0.7	1.4±0.3	1.9±0.07	1.4±0.3	1.4±0.9	0.3	1.2	1.7	1.4	1.9	1.6
P ppm/kg	1.4±0.3	1.6±0.3	1.6±0.4	1.6±0.3	1.4±0.1	1.6	1.3±0.4	2.3	1.9	1.8	1.8
K ppm/kg	0.56±0.2	0.56±2	0.72±0.0	0.56±0.2	0.71±0.1	0.6	0.41±0.	0.49	0.19	0.58	0.7

In general, there were high losses of C and N during storage. These findings were in agreement with the review done by Kulling *et al.* (2003) who reported that average C loss of about 40% was suggested for solid cattle manure, but the value could vary as a result of storage conditions (aeration, storage period and temperature), and manure characteristics (degradability and moisture content).

The ANOVA undertaken to compare the mean differences between indigenous cows and crossbreeds as well as the mean differences in feeding regimes (supplement vs. non-supplement) showed that there were no significant differences for all nutrients in the dung. These findings were in disagreement with those reported by Tesfaye *et al.* (2004) and Kulling *et al.* (2003). The reason could have been that in the current study feed supplementation was not concentrate feed, but working animals and milking cows were fed extra mineral salt and Teff straw.

5.4.7 Impact of manure management on the environment

There were variations in nutrient losses during manure collection, storage or processing and application (Kulling *et al.,* 2003; Rotz, 2004). The most important processes involved in the loss of nutrients were:

- leaching of soluble nutrients from urine, in particular N, K and S, and
- loss of gases during collection, storage and application of ammonia in particular.

A loss of 41% N from dung was reported by Lekasi *et al.* (1998) during the collection and composting of cattle dung for 144 days. In the Ethiopian highlands, local animals were taken out to graze in the fields during the day and kept in kraals near the homesteads at night. Kraals were permanently kept near homesteads to avoid theft. Therefore, there was a substantial loss of nutrients during the day when the animals were out grazing in the fields, especially through urine, because urine patches contained as much as 200 to 550 kg N/ha (Tittonell *et al.,* 2010). Volatilization of N might also be considered at 10 – 25% (Lekasi *et al.,* 1998). Loss through volatilization were dependent on the level of ventilation, depth of storage tanks and storage period (FAO, 2006), and often ranged between 5 and 35% of the total N excreted.

Overnight keeping of animals in kraals also contributed to nutrient losses since urine was not collected and beddings were sparsely used. Some of the nutrients in dung were also lost through leaching and surface runoff, due to trampling and poor drainage in the kraals (Harris and Yusuf, 2001). Some farmers (6%) who kept crossbred cattle used slurry storage for both dung and urine.

5.4.7.1 Greenhouse gas emissions in households

Estimates of CH_4 and N_2O emissions for cattle, shoats and equines were calculated based on IPCC (1996) greenhouse gas emission guidelines. Average number of livestock per household in 2009 was extracted from interviews with farmers during the socio-economic survey **(Table 5.9).** The emissions were calculated as: the emission factor per animal multiplied by the average number of animals in a household. The emission factors were based on the IPCC data (1996). This information was important in estimating the contribution of livestock per household to greenhouse gas emissions into the atmosphere. **Table 5.9** shows the concentration of CH_4 and N contributed by an average household in the study area.

Table 5.9: Average household methane and nitrogen emissions

Species	Average number per household	Methane emissions (kg/yr)			N from manure (kg/yr)
		Fermentation	Manure	Total	
Cattle	8.3	265.6	8.3	273.9	318.72
Shoats	4.3	21.5	0.73	22.2	46.44
Equines	2.1	29.4	2.67	32.1	83.16
Poultry	7.6	-	0.14	0.14	3.78
Total	**22.3**	**316.5**	**11.84**	**328.3**	**452.1**

(I). Methane (CH_4)

The global atmospheric concentration of CH_4 has increased from a pre-industrial value of about 715 ppb to 1 732 ppb in the early 1990s, and 1 774 ppb in 2005 (IPCC, 2007)**.** One of the most important sources of anthropogenic CH_4 is ruminant animals. They produce CH_4

during the normal enteric fermentation process. In the 1990s, it was estimated that ruminants were responsible for about 28% of all anthropogenic CH_4 emissions (Moss *et al.,* 2000; Kurihara *et al.,* 2002).

In the current study, the amount of CH_4 produced was estimated at 328.3 kg per year per household **(Table 5.9).** The most important ruminants in terms of CH_4 emissions were cattle which produced 82% of the household emissions. According to IPCC (2007) CH_4 was 25 times more powerful than CO_2 in global warming potential (GWP). Emissions of 1 million metric tons of CH_4 are equivalent to the emissions of 25 million metric tons of CO_2 called "equivalent CO_2" (CO_2e). This is the concentration of CO_2 that could cause the same level of radioactive force and concentration of greenhouse gases (IPCC, 2001). Therefore, the amount of CH_4 produced per household in the current study was estimated at 8.2 metric tons of CO_2e per household per annum. The reference value adopted for the emission factor per animal was taken from IPCC (1996), which has an uncertainty of 20% in the value. The average household size was 6.2, thus the amount of CO_2e methane emission per capita per year was 1.3 tons. This rate alone was 30% higher than the total CO_2e for all GHG emissions reported in Ethiopia, and 1 ton per capita reported in 2005 (Wikipedia, 2011).

(II). Nitrous oxide (N_2O)

It was estimated that the global atmospheric concentration of N_2O increased from pre-industrial value of about 270 ppb to 319 ppb in 2005 (IPCC 2007). In 1998 the N_2O emissions from manure management systems were responsible for 26% of the total anthropogenic emissions of N_2O (Kroeze and Mosier, 2002; Hickmen e*t al.,* 2011). The N_2O emission from domestic livestock in the study area was calculated based on the average number of livestock per household and GHG emission inventory guidelines from IPCC (1996).

Therefore, the N_2O released per household was estimated as: 452.1(N) x 0.02(EF) = 9.04 kg N_2O emissions/annum/household. The emission of 1 million metric tons of N_2O was equivalent to the emissions of 298 million metric tons of CO_2 (IPCC, 2001). In the current study, the CO_2 equivalent of N_2O emitted from manure was 2 694 kg /annum /household or 0.4 tons CO2e emissions per capita per year.

The N content of fresh manure in the present study was 1.9%, while Tesfaye *et al.* (2004) reported from similar agro-ecology zone a value of 0.42% from ashes of burnt dung. The difference of 1.48% N was the amount of N lost as N_2O, NO_3 and NH_4. Thus, the amount of N lost per household per day was 81.4 g N (i.e. 1.48% N x 5.5 kg/day). When this was converted to N_2O it was 360.3 g N_2O emissions into the environment per household per day (i.e. 81.4 g N x 4.4263 conversion factor).

Africa contributed 15.5% of the total global anthropogenic emissions of N_2O in 2005, which was equivalent to 1500 Gg N_2O when Africa had an estimated 1 billion people (Hickmen *et al.,* 2011). Thus, based on 2005 data N_2O production per capita per annum for Africa was estimated at 1.5 kg. According to the current study, a household size of 6 people produced 0.3633 kg/d x 365.25 days = 132.7 kg. Thus, N_2O production in the current study was estimated at 22 kg per capita per annum. This was 15 fold higher than per capita emissions in Africa. The estimates of N_2O were based on the IPCC guidelines. Although IPCC guidelines provided an initial estimate, the current default values and assumptions of the IPCC are unlikely to accurately estimate emissions in Africa (Hickmen *et al.,* 2011).

(iii) Carbon (C)

About 94% of the respondents in the current study used manure for cooking fuel. When manure was burnt directly, most of the organic compounds such as C, N and S were lost to the atmosphere, which contributed to greenhouse gas emissions (FAO, 2002) and other nutrients were recycled on arable land through the spread of the ashes in the fields.

Eighty percent of the respondents said that they used manure aged between 6 to 12 months for cooking fuel. The C fraction of 6 to 12 months old manure was found to be 36.6% OM. Assuming there was 55% C in the OM of manure (Hansen *et al.,* 2006), and a C factor of 0.2013, the DM fraction would be 0.972. The average amount of manure burnt per day for 3 years as reported in the current study was 1.57 kg/day/household. Thus, the annual carbon emitted per household due to the burning of manure was calculated as:

C (kg emissions/household/year) = 0.2013 x 0.972 x 1.57 kg/day x 365.25 days

= 112.20 kg C emitted /household/year

It was also estimated that the global atmospheric concentration of CO_2 increased from a pre-industrial value of about 280 ppm to 379 ppm in 2005. The annual CO_2 concentration growth rate was larger from 1995 to 2005, an average of 1.9 ppm/year (IPCC, 2007). To convert C to CO_2, a factor of 3.67 (i.e. 44/12) was used (CO_2 Information Analysis Centre, 2007). Therefore, the amount of CO_2 released per household from the burning of manure was 122.20 kg C x 3.67 = 381.48 kg CO_2/household. The world CO_2 emissions per capita per annum in 2006 were estimated at 4 180 kg CO_2 (IPCC, 2007).

Thus, with an average of 6.2 people per household CO_2 emission was estimated at 61.50 kg CO_2. In the USA (the highest carbon emitter), CO_2 emissions in 2006 from human activities were estimated at 18 600 kg CO_2 per capita (IPCC 2007). The comparison showed that the use of manure as fuel in the study area had no significant effect on CO_2 emissions per capita, but they had a negative impact in terms of nutrient recycling, soil carbon sequestration and soil fertility. Therefore, for improved yield and healthy eco-systems burning of manure has to be substituted by other alternative energy sources such as bio-gas (FAO, 2001).

Overall, livestock and manure management systems contributed a lot to GHG emissions. The total CO_2e gas emitted per household per annum by livestock, manure management and burning was estimated at 11, 276 kg CO_2e (i.e. 8 200 kg CO_2e from CH_4, 2 694 CO_2e from N_2O and 381.48 kg CO_2e from CO_2 from burning manure) which was about 2 tons CO_2e per capita per year. The CO_2e emission rate in this study was twice the one reported by Wikipedia (2011) for Ethiopia's per capita emission in 2005. Had other anthropogenic and natural GHG emissions been added to this CO_2e value, the total amount of CO_2e gases released per capita in Ethiopia would be alarming. This calls for more research to estimate GHG emissions at household level and grass root level. Under the household level GHG the largest CO_2e emissions were from CH_4 (72.6%), N_2O (24%) and C (3.4%) which showed that there is an urgent need to improve livestock and manure management systems under smallholder agriculture.

In 1998, Ethiopia ranked 18th globally in terms of CH_4 emissions from livestock and 10th in N_2O emissions from manure management (WRI-CAIT, 2012). The ranking in N_2O emissions went up from 13th in the 1980s to 10th in 1998 (WRI-CAIT, 2012). This **e**vidence indicated that due attention should be given to reduce N_2O emissions by improving manure management at grass root level.

5.5 Conclusions and recommendations

On the average, the number of livestock per household for most species increased during the Derge regime in the 1990s compared to the Haile Sellassie regime in the 1970s when people did not own land; and then the number declined in the 2000s except for equines, crossbreeds and oxen. The change to crop intensification led to the change in the purpose for livestock keeping. Farmers started keeping certain animals for specific purposes unlike before when livestock was kept for prestige and economic security. The major drive for the change in attitude towards the purpose of keeping livestock was scarcity of resources, mainly feed and water. Equine ownership has significantly increased due to their low off-take rate and their feeding habits which allowed them to survive in harsh environments where feed resources were extremely scarce.

Out of the total manure produced per household, two thirds was used for household fuel energy consumption and one third was sold to generate extra income. About 93% of the respondents said that they collected manure for household fuel needs, but only 24% of that was sold to generate extra income. All manure was collected by women and children. Homestead manure was collected early in the morning before animals went out to graze in the fields. Manure was collected in one place and pan-caked after mixing with straw. Women did pan-caking and storage of the manure. Straw enabled the manure to be moulded into pancakes, and it also made it easier to store and ignite.

Manure heaps were domed with conical shapes that narrowed at the tips in order to protect the manure from rain water and sunlight. The quality of manure was affected by environmental factors such as rain (32%), insects and rodents (31%); and humidity (30%) during storage. Rain made manure wet and difficult to burn. Poor storage led to fungal development and infestation by insects and rodents. There were high losses of C and N through leaching and gas emissions during storage.

Although it was commonly assumed that manure was used for fertilizer, the bulk of it was actually used for cooking fuel. There was a significant difference in crop response to manure application. Vegetables produced higher yields with manure than chemical fertilizers. Cereals responded more to chemical fertilizers than to manure. Therefore, combining manure and chemical fertilizers was the best option for the sustainability of crop production in the area. Some of the limitations to the use of manure as an organic fertilizer were inadequate manure production, high labour cost, bulkiness and high cost of transport to the fields and weed infestation. Manure management systems in the study area were affected by livestock husbandry practices. Only crossbred cattle (5%) were zero-grazed and used; and manure was stored in pits as slurry. Indigenous cattle were grazed outdoors in the fields during the day and at night they were kept in kraals near homesteads. There was a substantial loss of nutrients during the day when animals were grazing in the fields through leaching and trampling of dung and urine patches. Indoor or zero grazing of livestock could reduce nutrient losses.

The use of manure as fuel in the study area had no significant effect on CO_2 emissions at household or local level, but had a negative impact on SOC storage and soil fertility. Therefore, for improved yield and balanced eco-systems manure burning has to be replaced by other alternative energy sources such as bio-gas and kerosene. The largest carbon equivalent emissions were from CH_4 (72.6%), N_2O (24%) and CO_2 (3.4%) which indicated the need to improve livestock and manure management systems under smallholder agriculture. New dietary strategies are in place in some developed countries for the reduction of CH_4 emissions from ruminants by manipulating ruminal fermentation directly to inhibit methanogens and protozoa or to divert hydrogen ions away from methanogens. By contrast, in developing countries, change in feeding systems, breed selection, good animal husbandry and improved take-off were identified as viable options for the reduction of greenhouse gas emissions. However, existing mitigation strategies for CH_4 emissions in dairy production, such as the use of high quality forages and increased use of grains were recommended management practices in the current study.

CHAPTER 6:

THE CONTRIBUTION OF LIVESTOCK AND ANTHROPOGENIC FACTORS TO HEAVY METAL LOAD

6.1 Introduction

Heavy metals are those that are found in the soil in both trace amounts and elevated concentrations to the point of being toxic to plants and animals in some cases (Alloway, 1994). They are listed as Cadmium (Cd), Chromium (Cr), Cobalt (Co), Copper (Cu), Mercury (Hg), Manganese (Mn), Molybdenum (Mo), Nickel (Ni), Lead (Pb), Selenium (Se) and Zinc (Zn). Toxic elements can be classified as those elements that may have adverse effects on crops and ultimately on consumers of produce (Alloway, 1994; Gupta and Gupta, 1998). Although each country has its own regulations and standards of the maximum allowable concentrations, the levels that are generally accepted are those of the European Commission directive No 1881/2006 and No 629/2008, and US Food and Drug Administration (FDA, 2000). Typical concentration levels for some metals found in soils that are not considered contaminated and do not have parent material that is high in these metals are: 20 mg/kg Cu, 1 mg Cd/kg, 50 mg/kg Ni, 25 mg/kg Pb, and 50 mg/kg Zn (Forstner, 1993).

The contamination is a hazard when the available fraction of heavy metals readily mobilized in the soil environment are taken up by plant roots that eventually affect livestock and humans who consume different plant parts as well as grains (Chaney *et al.,* 1993). Research on heavy metals availability is a very important activity because it investigates the risk of movement of these metals down the soil profiles and the subsequent contamination of underground water deposits (Christensen *et al.,* 1996; Antoniadis, 1998). The availability of metals to crops is also related to the accumulation of metals in the food chain at levels that are potentially hazardous.

In Ethiopia heavy metal availability to crops may occur after irrigation with water from rivers that are contaminated with factory effluents. This has been studied by many investigators in the past (Fisseha, 1998; Tamiru, 2001; 2006; Fisseha, 2002; Fisseha and Olsson, 2004;

Amare, 2007), but the role of different local agricultural practices in enhancing heavy metal accumulation as well as the level of heavy metal accumulation under smallholder farming systems has not been well documented.

Many researchers have investigated the possibility of downward movement of heavy metals in soil profiles and have come up with different findings (Antoniadis, 1998). Some investigators thought that heavy metals were not supposed to move very deep into the soil profiles (Antoniadis, 1998), while others found that there were certain conditions that could facilitate the movement of heavy metals deep into the soil profiles (Kabata-Pendias, 2007). These conditions include acidic soil environment, unsafe agricultural practices, soil texture such as sandy soils with low absorption capacity, and high concentration of heavy metals in the topsoil (Kabata-Pendias, 2007).

Preliminary studies on heavy metals in Ethiopia indicated that there were increasing trends of heavy metal uptake by vegetables grown on farms contaminated with heavy metals from irrigation water or other pollutants (Fisseha, 1998; Fisseha and Olsson, 2004; Tamiru, 2006; Amare, 2007). Therefore, there is a growing concern about food quality and safety when agricultural products are obtained from contaminated soils. Soils under repeated contamination from different pollutants eventually lose their resilience and are unable to provide good quality food products (Antoniadis, 1998). They become hazardous to both human and livestock health and as well as the environment. An appraisal of the extent of contamination in urban and rural farms is of paramount importance and should recommend alternative remediation measures (During *et al.,* 2003).

In the current study six heavy metals (Cu, Fe, Mn, Ni, Pb and Zn) were assessed. Fe and Zn are very important and mobile elements which have been widely studied. Ni, like Zn, is mobile in the soil and it is also essential for plant growth, while Pb (although a relatively immobile metal) is considered a very serious environmental contaminant (Kabata-Pendias, 2007). In the light of all the above, soil samples were collected and examined for the effect of different practices on heavy metal load under smallholder farming. The role of different organic sources, land management practices, soil texture and soil tillage were taken into account to evaluate the level of heavy metal load on soils in the study area. The impact of factory effluents on heavy metal load in the soil was assessed to highlight the risk of future industrial expansion on the local environment.

Therefore, the purpose of this study was to: (a) assess the effects of factory effluents on the heavy metal load on smallholder farms; (b) compare the level of heavy metal concentrations under the influence of different natural and anthropogenic factors (land use, soil texture and tillage type); and (c) highlight the leaching of heavy metals to the lower soil profiles and the role played by organic carbon.

6.2 Materials and methods

6.2.1 Location of sites

Adaa district lies between longitudes 38^o 51’ to 39^o 04’ E and latitudes 8^o 46’ to 8^o 59’ N, covering an area of 1750 km^2 east of Addis Ababa. Most of the land (90%) is plain highlands ranging between 1600 to 2000 m above sea level, and the remaining area is mountainous. The district is characterized by subtropical climate and receives about 860 mm rain per annum. In general, the main rainy season occurs between mid-June and September, followed by a short dry season that might be interrupted by the short rainy season in February and March (Kahsay, 2004).

Mean annual temperature ranged from about 8 to 28°C. Black clay vertisol soils were the dominant soil type, which are fertile but difficult to work on because of water logging. The average household farm size varied from 1 to 2.5 ha and the major farm operations were done by draught oxen power. The main farming systems were mixed crops and livestock production systems. Livestock farming included dairying, cattle/oxen fattening, poultry and small ruminant rearing. Apiculture was emerging in some areas like the vegetative mountain areas. The population of the district was estimated at 300 000 people, of which 50% were rural people whose livelihoods were based on agriculture (IPMS, 2004).

6.2.2 Soil sample categories

The total sample sites were 15 as shown in **Table 6.1.** Soil samples were taken at the depths of 0 to 15 cm and 15 to 30 cm. Four subsamples were taken from each sample site. Subsamples of each site were mixed in one bag to form a pooled sample. The sample sites were grouped in the four categories according to (a) tillage type, (b) land use, (c) soil texture, and (d) organic sources of fertilizer.

Table 6.1: Sample sites and their characteristics

Case No:	Sample site	Tillage type	Land use	Soil texture (15-30 cm)	Organic sources of fertilizer
1	DZ Research Centre	Uncultivated	Undisturbed	Silt loam	None
2	Private commercial farm	Deep tillage	Crop land	Sandy loam	Animal
3	Crop rotation plot	Shallow tillage	Crop land	Loam	Plant
4	Minimum tillage	Minimum tillage	Crop land	Clay loam	Plant
5	Farmyard manure plot	Shallow tillage	Crop land	Clay loam	Animal
6	Compost plot	Shallow tillage	Crop land	Loam	Plant
7	Recycling residue	Shallow tillage	Crop land	Clay loam	Plant
8	Communal grazing	Uncultivated	Grazing	Sandy loam	Animal
9	Fenced off	Uncultivated	Undisturbed	Loam	None
10	Mechanized farming	Deep tillage	Crop land	Loam	None
11	Effluent contaminated	Shallow tillage	Chemical	Clay loam	None
12	Effluent contaminated	Shallow tillage	Chemical	Clay loam	None
13	Effluent contaminated	Shallow tillage	Chemical	Silt loam	None
14	Abattoir waste disposal	Uncultivated	Chemical	Sandy loam	Animal
15	Swamp/wetland	Uncultivated	Seasonal grazing	Silt loam	Animal

Each category of sites was further analyzed using indicators selected by stakeholders (farmers, experts and the investigator). Thus, tillage type was further broken down into: (a) Deep tillage (N = 2) which was defined as mechanized tillage with a tractor-mounted disc or moldboard plough at the depth of >20 cm. This was predominantly used by commercial farms and well off farmers; (b) Minimum tillage (N =1) which was ploughed using draught oxen power before herbicides were used to remove weeds just before sowing. This type of ploughing was rarely applied in the district; (c) Shallow tillage (N = 7) which involved draught oxen plough at a depth of 15 to 18 cm with 3 – 5 follow up ploughing depending on the type of crops. Shallow tillage was widely used in the district, and (d) Uncultivated land (N = 5) which was never ploughed for over 3 decades.

The sites were also categorized according to their land uses, namely; (a) Sites with chemical effluents (N = 4) from factory outlets such as detergents, steel and food processing; (b) Grazing land (N = 2) which were communal grazing lands allocated for livestock grazing only; (c) Crop land (N = 7) which was solely used for crop production for more than 3 decades; and (d) Undisturbed land (N = 2) which was free from human and animal interference for more than 3 decades, e.g. areas fenced off for biodiversity conservation.

Four major texture classes were identified in the study area through laboratory analysis. Their composition was defined using the USDA texture triangle. The four soil textures were listed as: loam, silt loam, clay loam and sandy loam. Soil textures were analyzed according the methods described by Bouyoucos (1951) and cited in the laboratory manual prepared by Tadesse *et al.* (1991).

The other grouping of the sample sites was the three classes of organic sources of fertilizer such as; (a) animal debris (N = 5) from slaughter house waste and manure; (b) plant debris (N = 4) which included decayed crop residues and compost; and (c) non-organic sources (N = 6) which had no external organic additions either from plant or animal sources. The above classifications were used in the statistical analysis of heavy metal loads in soils and their mobility.

6.2.3 Sampling and chemical analysis

Fifteen soil samples were collected from different locations in May 2009, based on the different land uses and agricultural activities in the study area just before the major cropping season (June/Sept). The sites were grouped according to different agricultural activities in the area such as: factory effluent discharge areas, municipal waste disposal areas, fenced areas, and the types of fertilizers used (organic or chemical). Each soil sample was taken from the plough layers (0-15 cm and 15-30 cm). Four subsamples were taken from each site at a radius of 30 to 50 m distance and pooled together as composite samples to represent the conditions of the area. At the end, 15 pooled samples were obtained for chemical analysis.

The pooled samples were air dried at ambient temperature and crushed to pass through a 2 mm sieve first; and then the pooled samples were thoroughly mixed and ground to pass through a 0.149 mm sieve; and stored in plastic bags prior to the chemical analysis. The pooled samples were analyzed for Fe, Mn, Ni, Cu, Zn and Pb. All the micro-nutrients were determined using DTPA extract through Atomic Absorption Spectrometer (Tadesse *et al.,* 1991). Soil pH was determined using a pH meter with a soil/water ratio of 1: 2.5. Available P was extracted according to the method described by Olsen *et al. (*1954).

The organic content in the soil was determined based on the method described by Walkley and Black (1934). CEC was determined using ammonia distillation (Chapman, 1965). Exchangeable bases were measured using 1N ammonium acetate per unit of meq/100 g of soil (Tadesse *et al.,* 1991). The soil texture proportions were determined using Bouyoucos (1951) method.

6.2.4 Statistical analysis

Statistical analysis and graphs were done using SPSS version 17.0.1 (2008). General linear model (GLM) was used to compare the mean differences of the different groups. Analysis of variance was also done. The univariate analysis was used to compute mean, standard deviation and frequency.

Cluster analysis was used in the grouping of different sample sites with various levels of heavy metal content in the soil. Cluster analysis or clustering is the task of assigning a set of objects into groups (clusters) so that the objects in the same cluster were more similar to each other than those in other clusters (Everitt *et al.,* 2001). At different distances, different clusters formed a dendrogram or hierarchical clustering (Manly, 2005). In the current study, Euclidian distance which is the most commonly selected type of distance was used (Everitt *et al.,* 2001). It was the most preferred unit for the geometric distance in the multidimensional space; and it was computed as:

Distance (x,y) = $\{\sum_i (x_i - y_i)^2\}^{½}$

In the dendrogram, the X-axis marked the distance at which the clusters merged, while the objects were placed along the Y-axis so that the clusters did not mix. Popular choices are known as single-linkage clustering that use minimum distance between objects (Everitt *et al.,* 2001).

6.3 Results and discussion

The concentrations of heavy metals in the soil and their impacts on ecosystems can be influenced by many factors such as parent material, climate and anthropogenic activities (Kabata-Pendias, 2007). Heavy metals may be added to soils in organic and inorganic fertilizers and pesticides, soil amendments (e.g. lime and gypsum) (Zarcinas *et al.,* 2004). Correlation analysis between heavy metals and fertility parameters assist in tracing the origins of elevated levels of heavy metals in the soil. This section explains the findings on the origin and level of heavy metals in the study area.

6.3.1 Origin of trace elements in soils in the study area

The most important consideration in the heavy metal identification in the soils was to determine the original sources such as natural weathering, industrial processing, use of metal components in commercial processes, aerial deposition of smelting materials, leaching from garbage and solid waste dumps, the application of animal products, or some other sources (Alloway, 1994).

Heavy metals in smallholder agriculture were mostly related to the addition of organic and inorganic fertilizers to the soil. Most of the materials were added to the soil for agricultural purposes such as manure, compost, ash, lime and other inorganic fertilizers. When heavy metals were applied at normal rates they did not affect overall concentrations of trace elements in the soil. However, when they were applied at a higher rate they raised the concentration of trace elements in the soil (Cheng, 2007). Other sources of inputs that increased the concentration of heavy metals in the soil included herbicides, fungicides, irrigation water, bio-solid application, dredged materials, fly ash, and municipal composts (Forstner, 1995).

In the current study, the cluster analysis classified sample sites into seven groups **(Figure 6.1)**, after assigning average weight based on Euclidian distance measurement for all variables (Everitt *et al.,* 2001). It was found that major sources of heavy metals were from sample sites 13, 14, 15, 9 and 3; which represented steel rolling factory effluent, municipal abattoir (animal waste disposal area), swamp land area (waste and animal carcasses disposal area); and fenced off grazing and crop lands under rotation, respectively. The results of the cluster analysis showed that the two major factors that contributed to heavy metal stock in the soils were anthropogenic factors such as the addition of factory effluents and organic products and natural factors such as soil sediments as shown in **Figure 6.1**.

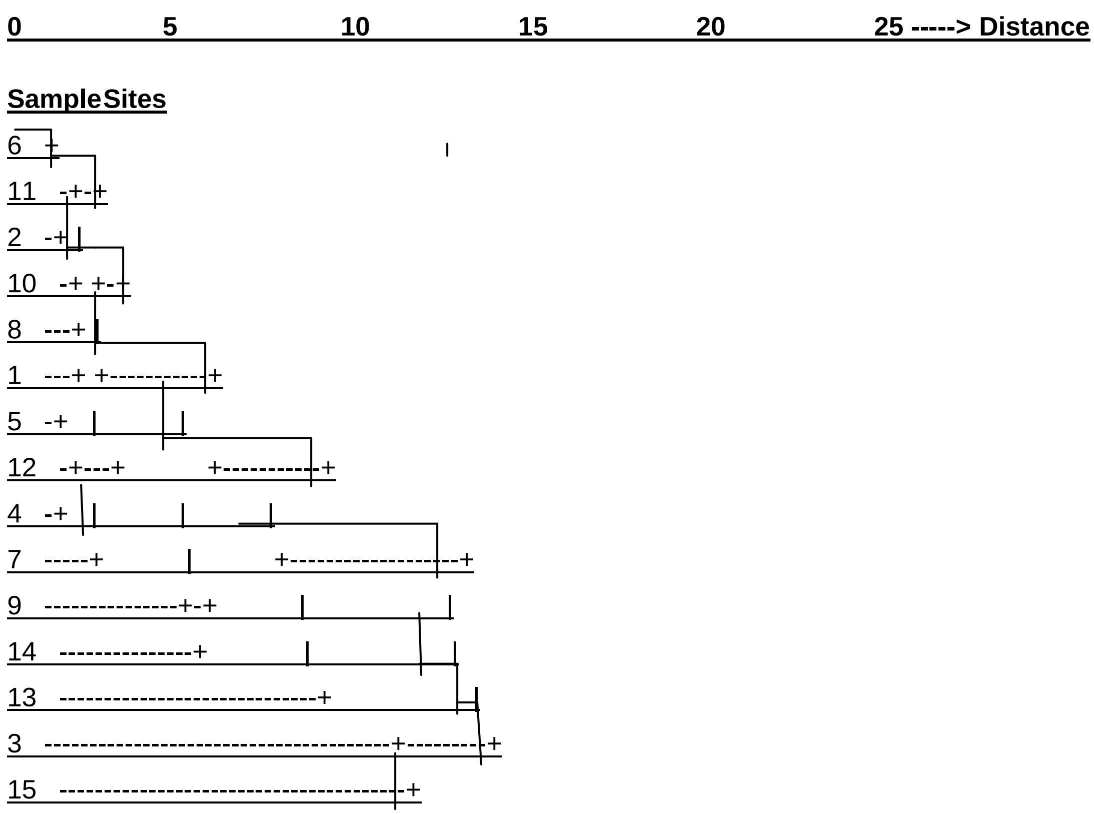

Figure 6.1: A dendrogram showing the hierarchy of cluster analysis

Sample means and standard deviations of the physical and chemical characteristics of heavy metal concentrations in the topsoil and subsoil samples in the study area are shown in **Table 6.2.** The pH of the topsoil was between 6.38 and 8.08 (average 7.00). The soils were slightly alkaline since 56% of samples had pH > 7.0. Rodriguez *et al.* (2008) reported that the pH was an essential factor that influenced the cation mobility and regulated the solubility of heavy metals in the soil because most of the metals tend to be available to plants in acidic pH. Higher soil pH is not favorable for the transfer of heavy metals from the soil to crops (Cheng, 2007). CEC refers to the preservation and supply of soil fertilizer and buffering capacity. The mean soil CEC in the study area was 46 ±12.4 mmol·kg^{-1}. The range was between 45.00 and 58.80 mmol·kg^{-1}, implying that the soil had higher CEC (Haque *et al.,* 1993) with moderate capacity to retain and maintain soil fertility. Soils in the study area had low SOM with an average of 12.00 g·kg^{-1}, which showed a declining trend compared to 34.8 g/kg which was reported by Tekalegn *et al.* (1988).

Table 6.2: Aggregated statistical value for important soil variables

Variables with soil depth	Mean	Std deviation	Minimum	Maximum
Soil carbon % at 0 - 15 cm	1.40	1.03	0.07	3.90
at 15-30 cm	0.99	0.73	0.07	2.48
Cation exchange at 0-15cm	44.95	14.22	14.80	58.80
Meq/100g at 15-30cm	46.88	10.58	27.80	58.80
Electrical cond. at 0-15cm	93.62	100.12	19.23	435.00
Mic.siem at 15-30cm	132.06	135.83	19.24	496.00
pH at 0-15cm	7.00	0.36	6.47	8.08
at 15-30cm	7.00	0.37	6.38	7.97
Available P (ppm) 0-15cm	31.94	33.54	7.92	137.19
at 15-30cm	37.17	66.87	3.75	271.88
Ca (ppm) at 0-15cm	21.54	8.37	7.05	36.33
Meq/100g at15-30cm	21.87	8.31	9.48	37.29

The SOC content in the study area showed a decline due to the imbalance in soil nutrient recycling under mixed crop and livestock production systems, because straw and crop residues were used for animal feed, construction and off-farm sales. In addition, dung was used as household cooking fuel and also sold for extra income instead of being used as an organic fertilizer (Haque *et al.,* 1993). Organic matter has been found to influence heavy metal absorption in soils due to the CEC of organic material (Kabata-Pendias, 2007). Thus, low SOC content in the study area contributed to low heavy metal availability to plants.

About 94% of the arable land in the study area had P deficiency (available P <10 $mg \cdot kg^{-1}$), and 67% of that had severe P deficiency (available P < 5 $mg \cdot kg^{-1}$) (Tekalgen and Haque, 1987). The trend of the available P showed a decline, since the available P content was <5 $mg \cdot kg^{-1}$ with an average of 3.2 $mg \cdot kg^{-1}$ as shown in **Table 6.2**. To compensate for P deficiency, large amounts of P fertilizer was the primary means of gaining higher yields in agriculture in the Ethiopian highlands (Haque *et al.,* 1993). However, excessive and inappropriate use of P fertilizer would inevitably lead to chemical and physical changes in soils (Cheng, 2007). In general, due to moderate alkalinity and CEC and low SOC; the soil did not favour the adsorption of heavy metals (Kabata-Pendias, 2007).

The overall available heavy metal concentrations were below the environmental quality standards as shown on **Table 6.3**. This implied that heavy metal load under smallholder farms were at a safe level at the present stage, but continuous livestock and human anthropogenic interventions were potential risk factors which may pose future health hazards. Although it looks safe at present; change in organic carbon content, tillage, land management and other human associated activities could enhance heavy metal loads in the soils.

Table 6.3: Comparison between heavy metal load in the study area and other locations

Element	Bulbula (Addis Ababa) Soil (total) (mg.kg $^{-1}$)	Kera (Addis Ababa) Soil (total) (mg.kg $^{-1}$)	Current study area Soil (total) (mg.kg^{-1})	Guidelines for metals above standard level Soil (total) (mg.kg^{-1})
Cu	38.96	55	40.5	100[a]
Fe	163.86	79.7	35.5	50000[b]
Mn	6587	3598	134.0	2000[b]
Ni	74.13	115	2.1	50[a]
Pb	46.47	110	2.6	100[a]
Zn	2985.5	263	53.5	300[a]

a b Values with prefixes are significantly different.
Sources: Fisseha (1998); Antoniadis (1998); Kabata-Pendias (2007)

6.3.2 Heavy metal load and additions from organic sources into the soil

In physical terms, organic matter improves the stability of soil aggregates resulting in better aeration of the soil and better water retention. It also improves the hydraulic conductivity as a result of increased number of soil macro-pores (Chaney *et al.,* 1993). Thus, it contributes to an increase in adsorption. Fulvic acid is an organic substance that has a lower molecular weight than humic acid, usually not more than 5,000 g mol^{-1}, that is found in organic compounds in the soil, and is often called dissolved organic carbon (DOC) (Antoniadis, 1998). Organic materials of low molecular weight easily dissolve in aqueous media within the pH range that is normally found in soils and they can be taken up by plant roots directly along with the metals that they have bound (Hamon *et al.,* 1995; Alloway, 1997).

In the current study, it was found that the relationship between organic sources of heavy metals (animal, plant and no-addition) and trace minerals was substantial. Cu, Zn and Ni had significant differences ($P<0.05$) due to different organic sources at the depth of 0 to 15 cm. However, there were no significant differences for Cu at a depth of 0 to 15 cm depth, between animal sources (0.50 ppm ± 0.43) and where there was no addition (0.51 ppm ±0.22); but there were a significant differences between plant (0.18 ppm ± 0.09) and the other two organic sources of heavy metals. This accumulation indicated that the contribution of plant debris to Cu load in the soil was low. In the case of Zn, there were significant differences between animal sources (0.86 ppm ± 0.58) and the other two organic sources (no organic addition -ve0.44 ppm ± 0.15 and plant sources -ve0.42 ppm ± 0.17). This demonstrated that livestock was an important contributor of Zn load at 0 to 15 cm soil depth. Ni was higher for plant sources than other organic sources as shown in **Table 6.4**.

There was no significant difference (P<0.05) for Pb, Mn and Fe at 0 to 15 cm soil depth from organic sources. However, there was a significant difference for Mn and Fe at P< 0.10. In the case of Mn there was a significant difference between plant sources (0.53 ppm ± 0.35) and animal sources (1.78 ppm ± 2.71) as well as between plant sources and where there was no addition (1.76 ppm ± 0.43). There were significant differences (P< 0.10) for Fe content between animal sources and where there was no organic addition; as well as between animal sources and plant sources. This illustrated that Fe from animal sources was an important contributor to metal loads at a depth of 0 to 15 cm **(Table 6.4).**

The heavy metal concentration was significantly influenced by organic sources at a depth of 15 to 30 cm, particularly for Fe and Zn. The mean Fe concentration at 15 to 30 cm depth from animal sources was 8.88 ppm ± 8.95 compared to 1.54 ppm ± 2.32 from plant sources, while soils without addition from any source had 2.41 ppm ± 1.76 **(Table 6.4).**

At the depth of 15 to 30 cm, the concentration of Zn was higher for animal sources (0.86 ppm ± 0.58) medium for no organic addition (0.44 ppm ± 0.15) and lower for plant sources (0.42 ppm ± 0.17). There was a significant difference for Zn between animal sources and the other two organic sources, but there was no significant difference between those without organic addition and plant sources. Other trace minerals Cu, Mn, Ni and Pb did not show any significant difference for different organic sources at 15 to 30 cm depth **(Table 6.4).**

Table 6.4: Heavy metal concentration from organic sources

		Organic sources		
Element	**Soil depth (cm)**	**Animal Source (N = 5) (ppm)**	**No fertilizer (N = 6) (ppm)**	**Plant source (N = 4) (ppm)**
Cu	0-15	0.50 ±0.43	0.51 ±0.22	0.18 ±0.09
	15-30	0.50 ±0.51	0.46 ±0.28	0.15 ±0.09
Fe	0-15	4.36 ±4.32	2.13 ±1.37	1.76 ±2.16
	15-30	8.88 ±8.95	2.41 ±1.76	1.54 ±2.32
Mn	0-15	1.78 ±2.71	1.76 ±0.43	0.53 ±0.35
	15-30	1.60 ±2.01	1.46 ±0.42	0.48 ±0.36
Zn	0.15	0.86 ±0.58	0.44 ±0.15	0.42 ±0.17
	15-30	0.75 ±0.51	0.04 ±0.01	0.38 ±0.19
Ni	0-15	0.01 ±0.01	0.04 ±0.01	0.01 ±0.01
	15-30	0.02 ±0.01	0.03 ±0.01	0.01 ±0.00
Pb	0-15	0.03 ±0.01	0.02 ±0.01	0.01 ±0.01
	15-30	0.02 ±0.01	0.03 ±0.01	0.02 ±0.01

The results showed that the contribution of livestock to heavy metal concentration was higher for Zn and Fe at both 0 to 15 cm and 15 to 30 cm soil depths as shown on **Table 6.4 and Figure 6.2.** In the present study, animal sources enhanced heavy metal mobility down the soil profiles (except for Pb) compared with the other two organic sources, mainly due to relatively high organic carbon content from animal sources. The carbon content of animal sources was 1.96% ± 1.32 at 0 to 15 cm and 1.57% ± 0.73 at 15 to 30 cm depth, while the carbon content of plant sources was 1.20% ± 0.92 at 0 to 15cm and 0.88% ± 0.42 at 15 to 30 cm depth; and that without organic addition was 1.06% ± 0.76 at 0 to 15 cm and 0.57% ± 0.64 at 15 to 30 cm depth. These findings are in agreement with the findings of Antoniadis (1998), who reported that the addition of high carbon sewage sludge enhanced trace element mobility down the soil profiles in Greece and the United Kingdom.

The level of mobility of heavy metals was higher for Fe and Zn compared with other heavy metals. **Figure 6.2** shows that heavy metal concentration was higher for soils with organic matter from animal sources than others at 0 to 15 cm soil depth. Dissolved organic compounds (DOC) were important in facilitating the transport of heavy metals into the soil profiles (Jardine *et al.,* 1992). Lee *et al.* (1997) reported that effluents from poultry litter containing high DOC accelerated Cd and Zn movement in the soil. Although the concentration of heavy metals was not a serious problem, caution should be taken to avoid any risks of future soil and ground water contamination, when adding organic compounds into the soil.

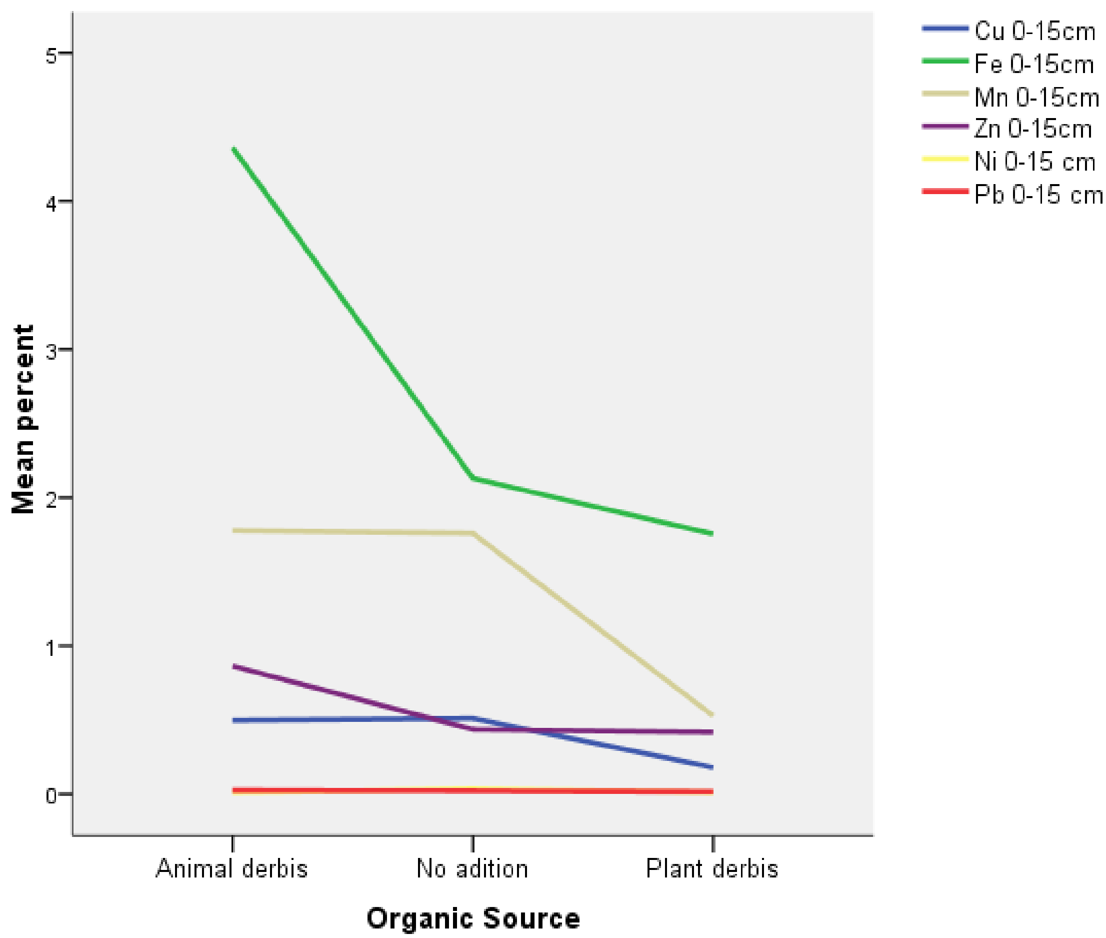

Figure 6.2: The proportion of heavy metals by organic sources at 0-15 cm soil depth

6.3.3 Heavy metal concentration and land use

The availability of metals in soils depends on their forms and concentrations in the parent material and their input through commercial fertilizer, manure, municipal waste, factory effluents and aerial deposition (Alloway, 1994). In the absence of pollutants, natural levels of metals in soils are influenced by the types of elements in rocks, weathering rate, organic matter content, soil texture and soil depth (Alloway, 1994). They are also influenced by leaching processes, adsorption and desorption from the solid phase. Thus, land use or ecological history of an area has an impact on the heavy metal concentration of that specific locality (Lee *et al.,* 1997; He *et al.,* 2005).

In the current study, the relationship between heavy metal concentrations and land uses gave different results for various categories as shown in **Table 6.5 and Figures 6.4 and 6.5**. At a depth of 0 to 15 cm there were no significant differences for Pb among the land uses. However, there was a significant difference ($P<0.05$) for other elements like Cu, Fe, Mn, Zn and Ni at the same depth. There were significant differences for Cu between the land use group and sites that had chemical discharges. The concentration of Cu from factory effluents, crop land, grazing land and the undisturbed site was 0.83 ppm ± 0.27, 0.28 ppm ± 0.14, 0.18 ppm ± 0.14 and 0.34 ppm ± 0.12, respectively. This demonstrated that Cu could be one of the chemical effluents from factories that may pose a threat regarding future pollution.

At a depth of 0 to 15 cm grazing land had a significant level of Fe compared with other land uses. The concentration of Fe was 7.70 ppm ± 3.95; 0.82 ppm ± 0.81; 3.80 ppm ± 2.26 and 2.60 ppm ±1.86; in grazing land, crop land, sites with chemical discharges and undisturbed sites, respectively. The relatively high Fe concentration in grazing land could be due to livestock manure and urine deposition during grazing. Crop land had the lowest iron concentration at 0 to 15 cm depth, which illustrated that crops with high Fe content like Teff might have drained a significant amount of Fe from the soil (Wondimu and Tekabe, 2001). Higher concentrations of Zn (1.26 ppm ± 0. 90) and Mn (3.73 ppm ± 3. 99) were found at 0 to 15 cm soil depth in undisturbed sites. This demonstrated that Zn and Mn concentrations were reduced in other land uses because of anthropogenic factors as shown in **Table 6.5** and **Figure 6.3**.

There were significant differences in Ni concentration (0.03 ppm ± 0.02) at 0 to 15 cm between sites with factory effluents and other ecological groups. The high Ni in sites with chemical discharges was an indication of a threat to farms situated near factories as shown in **Table 6.4 and Figure 6.3**. In general, chemical discharges from factories could be a future threat in the case of Ni and Cu at 0 to 15 cm depth, but the hazard is still far below the environmental standards.

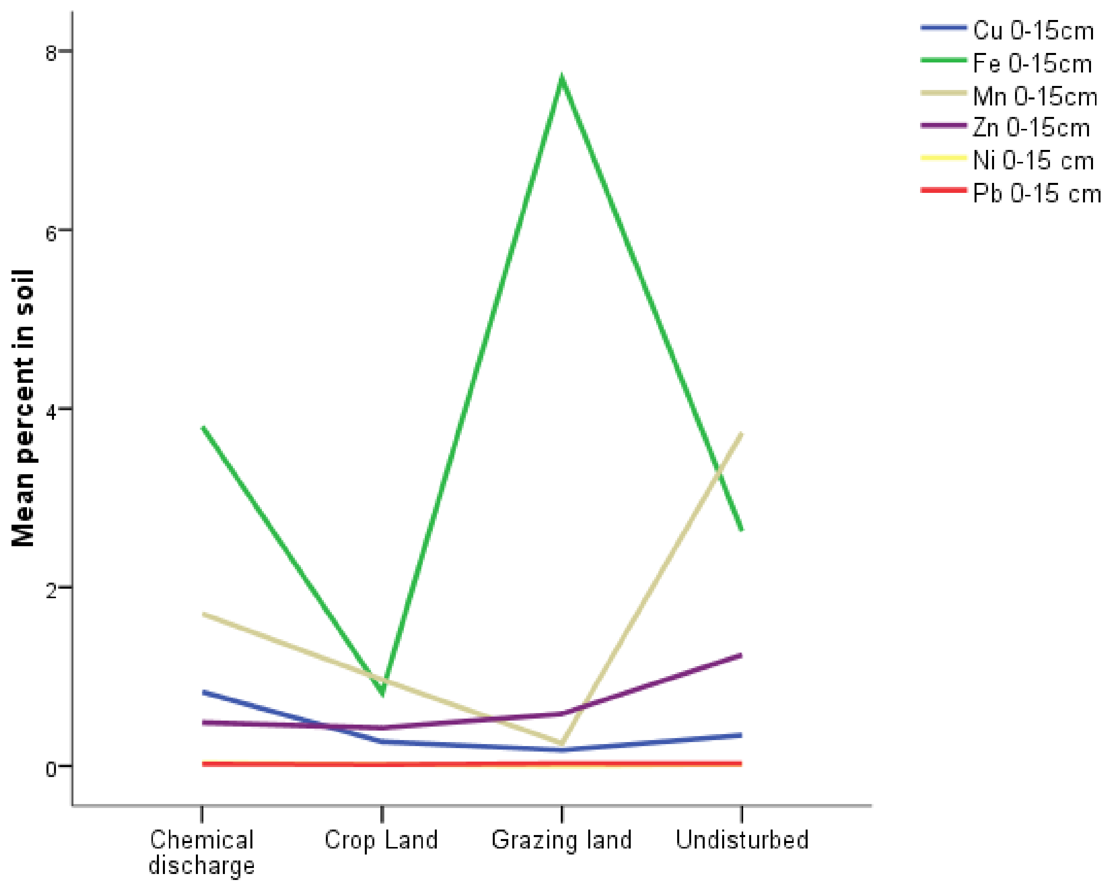

Figure 6.3: Micro-nutrient variations with land use at 0 to 15 cm depth

There were significant differences ($P<0.05$) in Cu, Fe, Mn and Zn concentration at 15 to 30 cm soil depth due to land use types. However, there were no significant differences in Ni and Pb concentration due to land use type at 15 - 30 cm soil depth. The concentration of Cu was significantly different between the sites with chemical discharges (0.79 ppm ± 0.36), crop land (0.17 ppm ± 0.11), grazing land (0.18 ppm ± 0.04); and the undisturbed sites (0.58 ppm ± 042).

At 15 to 30 cm depth, the concentration of Fe was significantly different in crop land (0.77 ppm ± 0.92), grazing land (6.30 ppm ± 1. 85), undisturbed site (10.30 ppm ± 13.22) and the site with chemical discharges (6.63 ppm ± 6.76). The highest Fe concentration was found in the undisturbed site and the lowest was in crop land. The data revealed that crops like Teff had absorbed a significant amount of Fe from the soil. The predominant crop in the study area was Teff, which covered about 40% of the total arable land (Kahsay, 2004).

The highest Mn concentration was found in undisturbed sites (2.92 ppm ± 3.01) and the lowest was found in grazing land (0.08 ppm ± 0.63). The sites with chemical discharges had intermediate Mn concentration (1.54 ppm ± 0.41), which illustrated that Mn concentration was not a threat to smallholder farms. Zn concentration was significantly different between the undisturbed site and the other three land use groups. There was a higher concentration of Zn at 15 to 30 cm depth for the undisturbed site (0.98 ppm ± 0.94) compared with the other three land use groups as shown in **Table 6.5.**

Table 6.5: Heavy metal concentration by land use and soil depth

		Land use/ Ecological history			
Element (ppm)	**Soil depth (cm)**	**Chemicals dumped on sites (N = 4)**	**Crop land (N = 7)**	**Grazing land (N = 2)**	**Undisturbed sites (N = 2)**
Cu	0-15	0.83 ±0.27	0.28 ±0.14	0.18 ±0.14	0.34 ±0.12
	15-30	0.79 ±0.36	0.17 ±0.11	0.18 ±0.04	0.58 ±0.42
Fe	0-15	3.8 ±2.26	0.82 ±0.81	7.70 ±3.95	2.60 ±1.86
	15-30	6.63 ±6.76	0.77 ±0.92	6.30 ±1.85	10.3 ±13.22
Mn	0-15	1.70 ±0.55	0.97 ±0.72	0.26 ±0.26	3.73 ±3.99
	15-30	1.54 ±0.41	0.73 ±0.52	0.08 ±0.63	2.92 ±3.01
Zn	0.15	0.49 ±0.16	0.43 ±0.18	0.59 ±0.15	1.26 ±0.90
	15-30	0.49 ±0.20	0.35 ±0.13	0.57 ±0.13	0.98 ±0.94
Ni	0-15	0.03 ±0.02	0.02 ±0.01	0.01 ±0.00	0.01 ±0.00
	15-30	0.03 ±0.01	0.02 ±0.01	0.00 ±0.00	0.03 ±0.02
Pb	0.15	0.02 ±0.01	0.02 ±0.01	0.03 ±0.01	0.03 ±0.02
	15-30	0.02 ±0.01	0.02 ±0.01	0.03 ±0.01	0.03 ±0.01

Overall, crop land had the lowest trace mineral content at both 0 to 15 cm and 15 to 30 cm soil depths. Some crops such as Teff removed more nutrients from the soil than others (Wondimu and Tekabe, 2001). This was in agreement with findings by Ketema (1997) who reported that Teff is a high micro-nutrient miner of Ca, Co, Zn, Al, Se and others. Tareke (2010) reported that with space planting of 20 x 20 cm and with the addition of NPK plus Zn, Cu, Mn and other micro-nutrients, Teff yield increased from 1.5 t/ha to 8.7 t/ha. This was an increase of 6 folds, in contrast with the traditional average yield of 1.2 t/ha. It was concluded that Teff varieties responded well to micro-nutrients such as Zn, Cu, Mg, and S (Tareke, 2010).

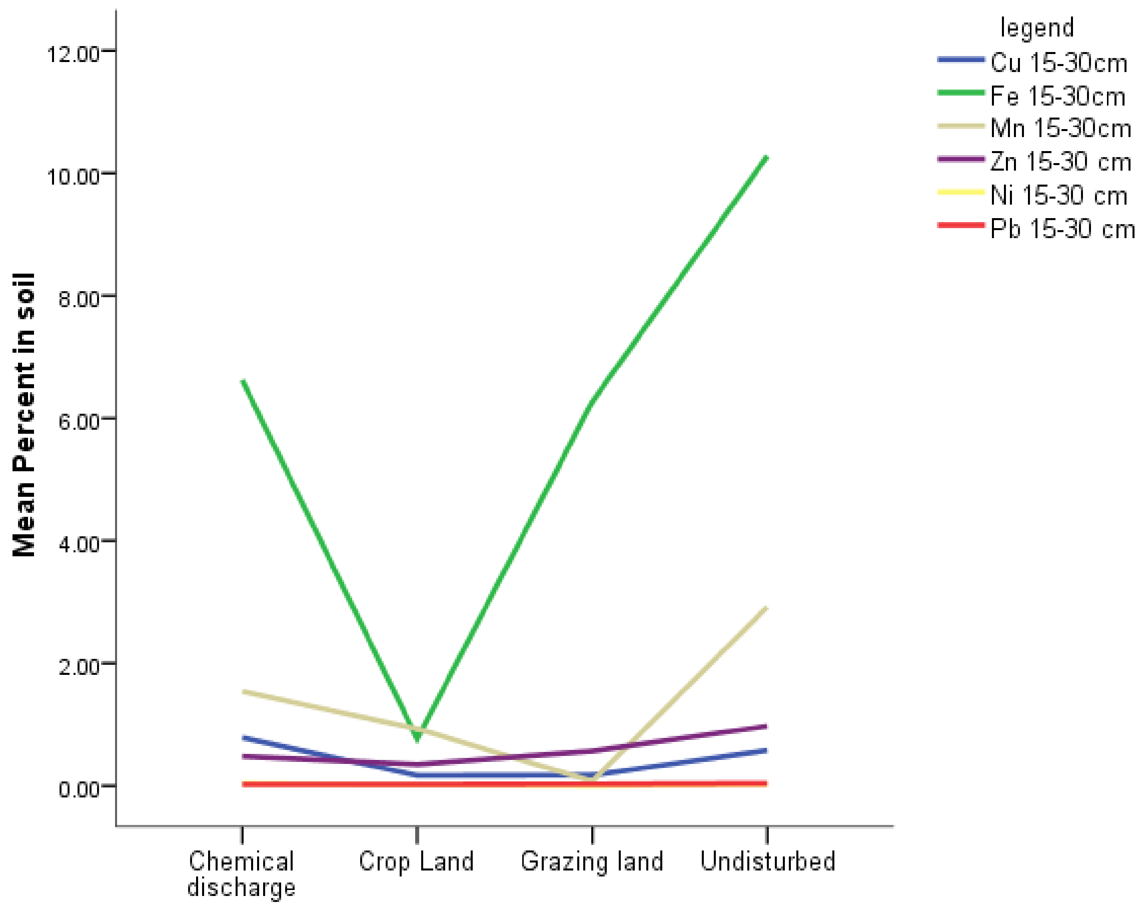

Figure 6.4: Micro-nutrient variations with land use at 15 to 30 cm depth

6.3.4 Heavy metal concentration and soil tillage type

Although the effects of tillage on nutrient concentration are limited but significant for heavy metals, Lavado *et al.* (2001) found that soybean was more sensitive to soil tillage than cereals. During *et al.* (2003) suggested that long-term no-tillage resulted in a significant increase in Cd and Zn, which were extracted by *Aqua regia* in a soil profile at 0 to 25 cm depth, especially at the 0 to 3 cm layer **(Table 6.6).**

In the present study, there was no significant difference in the concentration of Cu, Mn, Ni and Pb due to tillage type at both soil depths, while Fe and Zn was significantly influenced by tillage type at both depths. Uncultivated site contained 5.46 ppm ± 3.41 of Fe at 0 to 15 cm and 9.92 ppm ± 7.87 at 15to 30 cm; Zn was 1.25 ppm ± 0.90 at 0 to 15 cm and 0.98 ppm ± 0.94 at 15 to 30 cm depth. Deep cultivation had the lowest mineral concentration as shown in **Table 6 6.**

Table 6.6: Tillage type and concentration of heavy metals in small-scale farms

		Soil tillage type			
Element (ppm)	**Soil depth (cm)**	**Deep tillage (N = 2)**	**Minimum tillage (N = 1)**	**Shallow tillage (N = 7)**	**Uncultivated (N = 5)**
Cu	0-15	0.45 ±0.03	0.27	0.40 ±0.28	0.46 ±0.45
	15-30	0.21 ±0.01	0.30	0.34 ±0.34	0.54 ±0.47
Fe	0-15	0.29 ±0.10	1.68	1.72 ±1.51	5.46 ±3.41
	15-30	0.30 ±0.09	2.23	1.80 ±1.95	9.92 ±7.87
Mn	0-15	1.71 ±0.55	0.97	0.26 ±0.26	3.73 ±3.99
	15-30	1.54 ±0.41	0.93	0.08 ±0.06	2.92 ±3.01
Zn	0.15	0.49 ±0.16	0.43	0.59 ±0.15	1.25 ±0.90
	15-30	0.49 ±0.20	0.35	0.57 ±0.13	0.98 ±0.94
Ni	0-15	0.03 ±0.02	0.02	0.00	0.02 ±0.00
	15-30	0.04 ±0.01	0.02	0.00	0.03 ±0.02
Pb	0.15	0.02 ±0.01	0.02	0.03 ±0.01	0.03 ±0.02
	15-30	0.02 ±0.01	0.02	0.03 ±0.01	0.04 ±0.01

Figure 6.5 showed that most heavy metal concentrations were in the order of uncultivated > shallow cultivated > minimum cultivated > deep cultivated. A similar conclusion was reached by During *et al.* (2003) who reported that uncultivated soils were richer in heavy metals than conventionally tilled soils and they recommended that uncultivated soils should not be ameliorated with organic waste in the long term. Soares dos *et al.* (2003) reported that in an experiment conducted in Brazil, minimum tillage had a higher accumulation of heavy metals in soils than conventional tillage. The current study also confirmed that the depth of cultivation had an influence on the micro-nutrient content of soils. When adding organic matter to uncultivated soils, care has to be taken not to upset the balance of heavy metal load which may compromise their availability to plants.

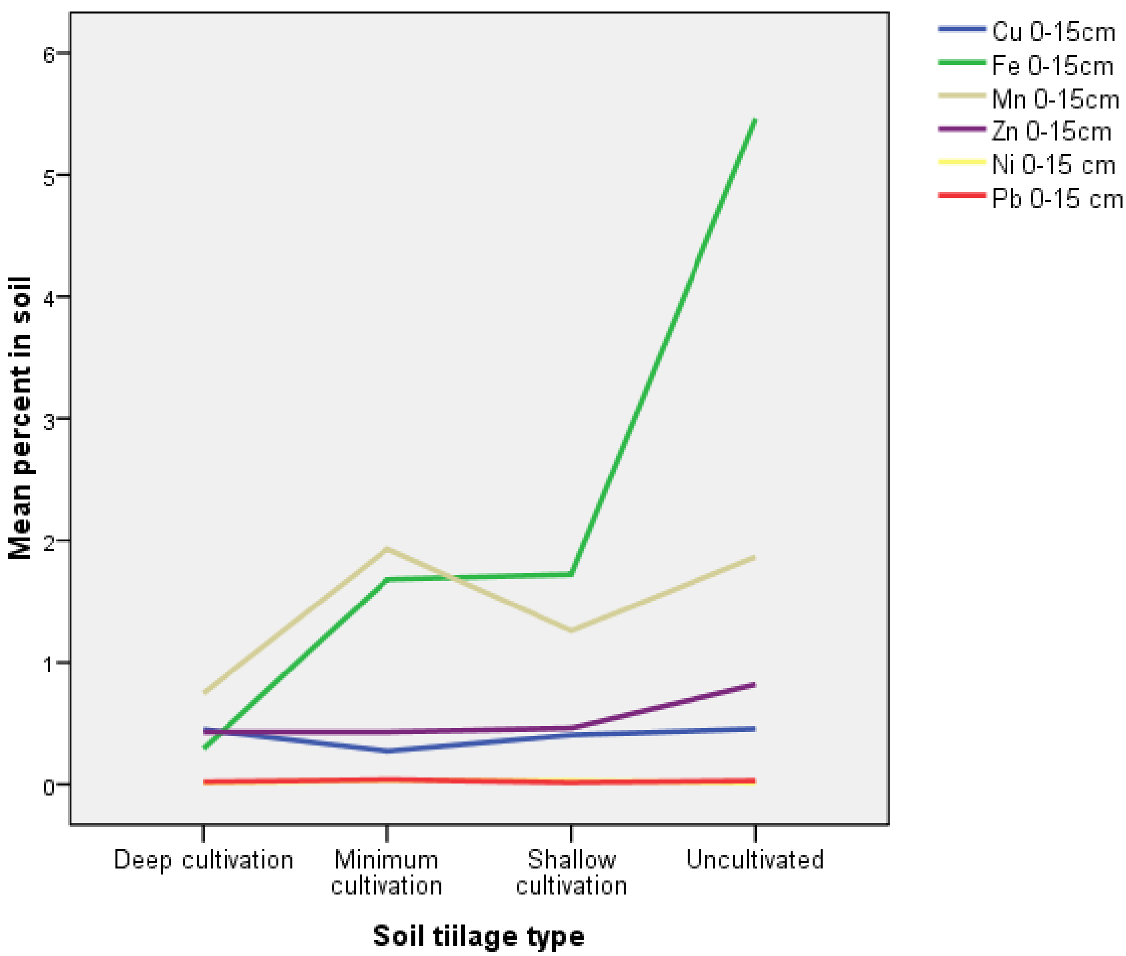

Figure 6.5: Micro-nutrient variations with soil tillage at 0 to 15 cm depth

6.3.5 Soil texture and heavy metal movement down the soil profile

The movement of heavy metals down the soil profile is of great importance, because it involves the risk of groundwater contamination and the deterioration of drinking water quality (Dowdy and Volk, 1983). Movement is often evident in high applications of heavy metals, usually in sewage sludge, in soils with low organic matter and clay content, in acidic conditions and when there is high rainfall or irrigation water has been applied (Dowdy and Volk, 1983; Christen *et al.,* 1996). Heavy metal concentration is influenced by soil texture, organic matter content and the accumulation of heavy metals in the soil (Haynes, 2005). The movement of heavy metals occurs through soil macro pores or cracks which is often referred to as preferential flow (Dowdy and Volk, 1983).

The literature provides cases of massive heavy metal movement up to 3 m depth (Lund *et al.,* 1976). There was, however, a disagreement about whether heavy metals move significantly under normal conditions or not (Zarcinas *et al.,* 2004). El-Hassanin *et al.* (1993) found that Cd, Zn and Pb only moved in the top layer and similarly, Smith (2008) reported slow heavy metal movement to the lower horizon. Chang *et al*. (1982) reported that four years after the termination of sewage sludge application, heavy metals were deposited only in the 0 to 15 cm top layer, while Harmsen (1977) found that Cd and Pb did not accumulate beyond 40 cm of the surface in a heavily contaminated Zn smelter area. Dowdy and Volk (1983) likewise, found that heavy metals did not move significantly below the incorporation zone or plough layer.

In the current study, the paired comparisons for the micro-nutrients at both soil depths showed no significant differences ($P < 0.05$) for all micro-nutrients at both depths except for Zn and Fe. It showed that the mobility of all heavy metals was uniform across all the soil textures except Fe and Zn as shown in **Table 6.7.** The movement of Fe was higher compared to other minerals. However, sandy loam had the highest accumulation of micro-nutrients at both depths compared with other soil textures. The high accumulation in sandy loam was due to the nature of the soil aggregates which allowed more concentration and mobility of nutrients as shown in **Table 6.7; and Figures 6.6 and 6.7.**

Table 6.7: Heavy metal concentration by soil texture in the study area

		Soil texture			
Element (ppm)	**Soil depth (cm)**	**Clay loam (N = 5)**	**Loam (N = 4)**	**Sandy loam (N = 3)**	**Silt loam (N = 3)**
Cu	0-15	0.46 ±0.28	0.31 ±0.14	0.33 ±0.26	0.74 ±0.49
	15-30	0.31 ±0.32	0.18 ±0.08	0.43 ±0.39	0.75 ±0.46
Fe	0-15	1.12 ±1.56	1.05 ±0.86	4.88 ±3.59	3.25 ±2.96
	15-30	1.91 ±2.17	1.84 ±2.25	9.19 ±9.74	6.83 ±8.41
Mn	0-15	1.27 ±0.96	1.14 ±0.97	1.98 ±2.71	1.14 ±0.22
	15-30	1.35 ±0.67	0.78 ±0.56	1.81 ±2.80	1.12 ±0.31
Zn	0.15	0.26 ±0.05	0.41 ±0.11	0.89 ±0.56	0.54 ±0.10
	15-30	0.35 ±0.12	0.39 ±0.21	0.88 ±0.67	0.52 ±0.20
Ni	0-15	0.09 ±0.02	0.02 ±0.01	0.02 ±0.02	0.02 ±0.02
	15-30	0.03 ±0.01	0.01 ±0.01	0.02 ±0.03	0.03 ±0.01
Pb	0.15	0.01 ±0.00	0.02 ±0.01	0.03 ±0.01	0.02 ±0.01
	15-30	0.02 ±0.01	0.03 ±0.01	0.03 ±0.01	0.03 ±0.01

The movement of heavy metals in the study area was in agreement with the results reported by Rodriguez *et al.* (2008) at a site where raw sewage had been applied for many decades. They found a uniform distribution of Cd, Zn and Ni throughout the soil profile, which was attributed to the movement of the metals down the soil profile. Although Pb is a relatively immobile element very strongly bound to the solid phase, but when applied in high quantities of up to 3.2 t/ha it was found that Pb moved to a depth of 75 cm (Williams *et al.,* 1980).

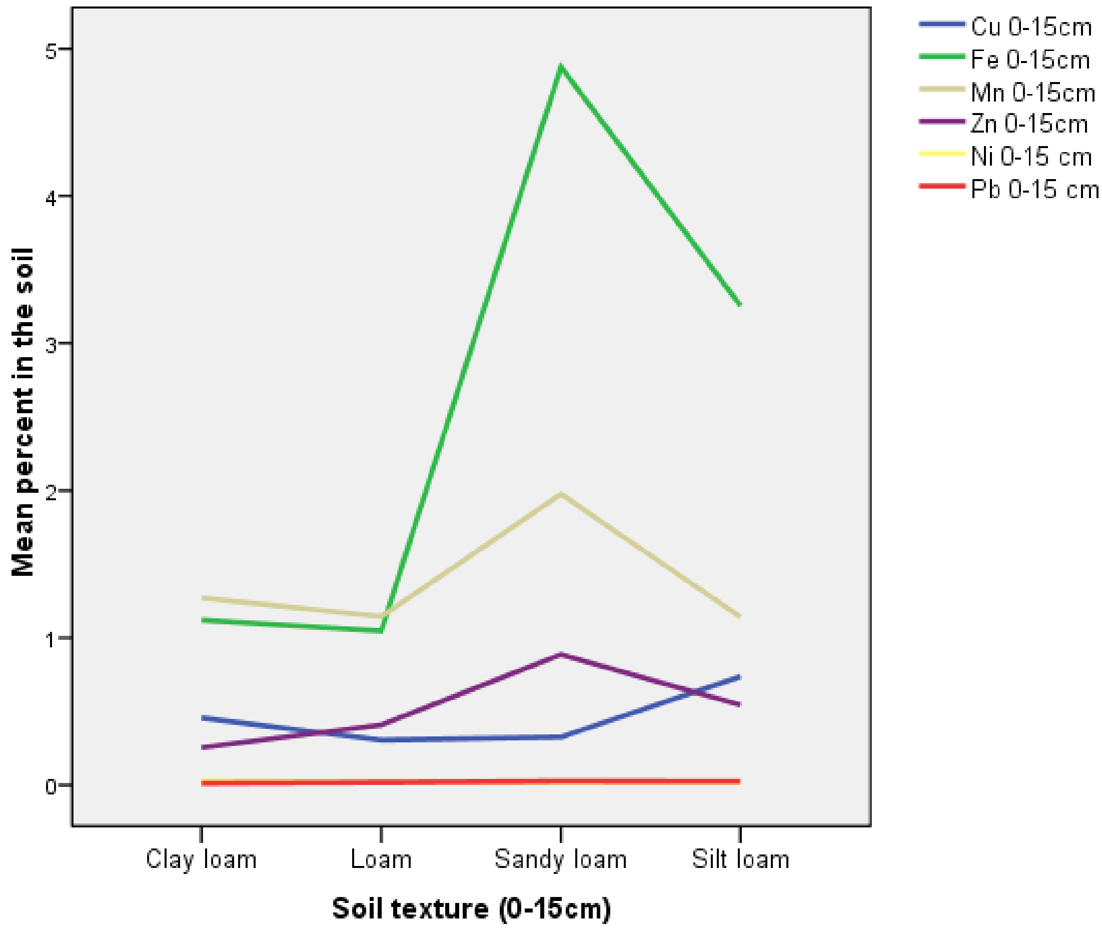

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Figure 6.6: Heavy metal concentration by soil texture at 0 to 15 cm depth

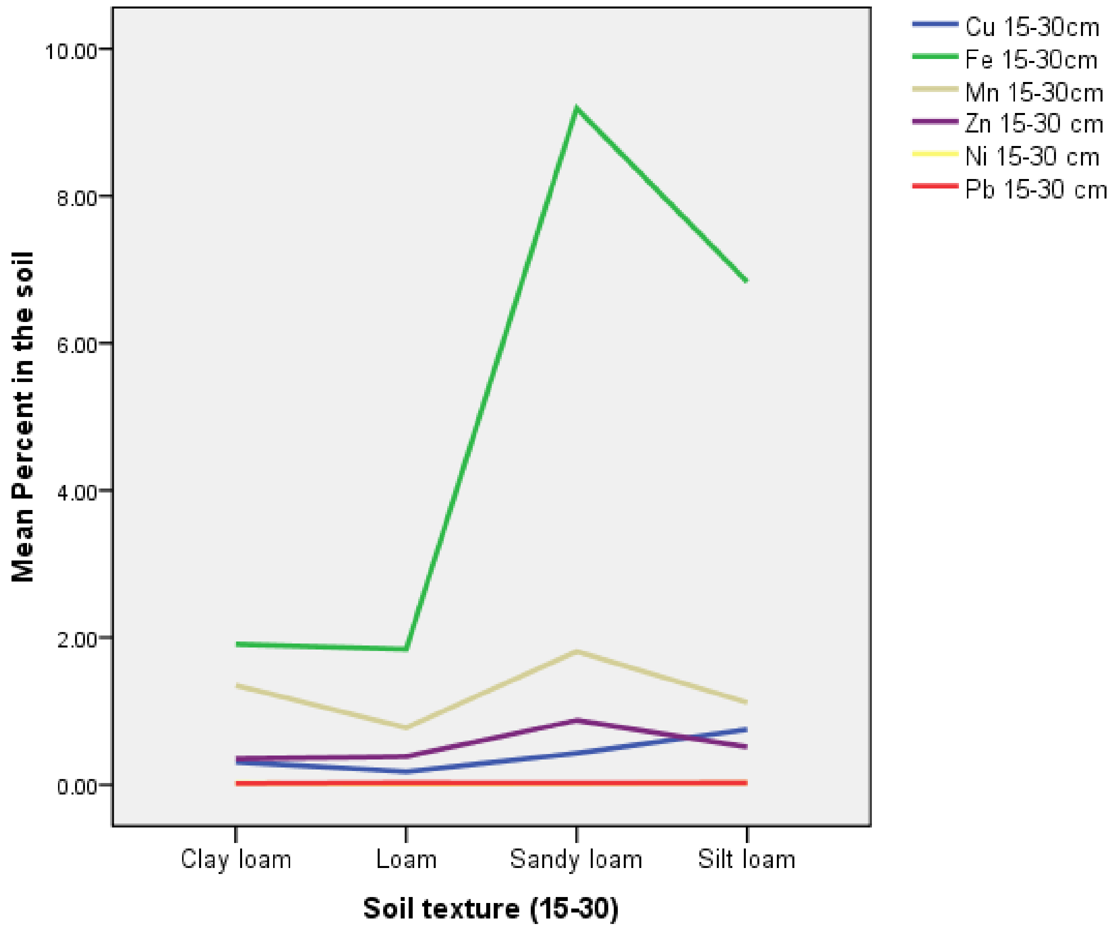

Figure 6.7: Heavy metal concentration by soil texture at 15 to 30 cm depth

6.4 Conclusions

Heavy metals occur naturally in the earth's crust but their anthropogenic release into the environment causes contamination problems related to them. In the present study, the heavy metal load in the soil was below the hazard level. Although their impact was negligible, this study revealed that contributors of heavy metals could be categorized as factory effluents and organic sources from animal products. The role of natural resources such as soil sediments, rocks and soil contents were insignificant. Anthropogenic factors such as tillage type also affected trace mineral concentration to a lesser extent, which increased with increasing ploughing depth.

Land use type had an effect on the concentration of heavy metals, particularly Fe which was lower in cultivated soils than in uncultivated soils. This showed that crops like Teff with higher Fe, Cu, Zn, Mn content in their grains extracted these minerals from the soil. Therefore, study on essential trace minerals in cereals growing the in highlands of Ethiopia is important for their supplementation to increase crop yield. Soil texture also had an impact on nutrient mobility in the soil profile. Sandy loam had a significant nutrient migration to the lower profile due to the porosity of the texture. Factory owners should take into consideration the characteristics of dump sites such as soil texture, organic matter content, soil pH, acidity, waste composition and the eventual accumulation of heavy metals.

Organic sources of heavy metals were found to be very useful in enhancing macro and micro nutrients availability to plants. In the present study, organic carbon in the soil was very low that it could have slowed the availability of trace minerals to plants. It was found that trace minerals were below the critical limit, thus addition of organic matter in the soil is vital for soil fertility improvement. Nutrient recycling through the application of manure, allowing crop residues to decay in fields, fallowing and rotational cropping should be practiced to rehabilitate arable lands. Minimum and zero tillage should also be recommended to build up soil nutrients.

CHAPTER 7:
LIVESTOCK AND WATER INTERACTIONS IN MIXED CROP AND LIVESTOCK PRODUCTION SYSTEMS

7.1 Introduction

The use of water for drinking and servicing animals is a basic need in livestock production (FAO, 2006). Like humans, livestock also need clean water for drinking to promote the required water intake for livestock productivity and for the control of water borne diseases (Luke, 1987). In the past, water quality concepts were applied mainly to crop production and human consumption (Peden *et al.,* 2006), while the idea of water quantity and quality for livestock productivity was usually ignored. The demand for milk and meat is likely to double in the next 20 years, if it grows by 2.5 to 4% per year (Delgado *et al.,* 1999), hence, water quality needs to be considered in the future for better livestock productivity.

Good water quality improves livestock productivity through enhanced metabolic processes in a healthy environment. Therefore, livestock not only requires clean water for drinking but for other related services such as cleaning of animals and farm facilities (barn, milk and meat equipment, abattoirs, milk processing plants, chicken dressing plants, etc.). However, water quality can also be affected by livestock, through the degradation and contamination of water resources when animals are poorly managed (Haile Sellassie *et al.,* 2006; Peden *et al.,* 2007). Livestock manure and urine pollute lakes, rivers and swamps, through the accumulation of NO_3 and other compounds, which degrade the quality of drinking water (MoWR, 2001). Factory effluents, chemical fertilizers, herbicides and pesticides in runoffs flow down streams, where they are deposited in rivers, swamps and lakes that lack proper soil conservation measures in the highlands (Sisay, 2007).

Livestock trampling and deforestation along water sheds and around lakes, rivers and swamps also contribute to the accumulation of silt and sediments in water bodies (Kahsay, 2004; Haile Sellassie *et al.,* 2006; Haile Sellassie *et al*., 2007). Aquatic life relies on the breakdown of organic material for primary and secondary sources of food. However, there is a limit to the amount of organic material that is acceptable in the aquatic environment

(Birenesh, 2007). Excess nutrients especially P and N in organic matter can trigger the growth of algae and weeds in water bodies, which could affect other aquatic organisms (Mateos, 2003; Solomon, 2006; Birenesh, 2007).

The other important water pollutant is factory effluents which flow into water bodies (Tamiru *et al.,* 2005), particularly in the central Ethiopian highlands where industrialization is on the rise (Sisay, 2007). Although Ethiopia is still at a low industrial development stage, about 80% of factories discharge their effluents in nearby water bodies without any form of prior treatment (Tamiru *et al.,* 2005; Solomon, 2006). In terms of both quantity and quality, industries cause severe pollution in urban streams and lakes (MoWR, 2001).

Moreover, 35% of the people who live in the city and towns have no access to sewage systems and clean toilet facilities. It is then obvious that surface water would be contaminated with human waste (MoWR, 2002). And since a very large population has no other sources of water for domestic, agricultural or livestock use, it is not surprising to see both acute and chronic water borne disease epidemics in rural and urban areas (MOWR, 2002).

Adaa district which was the study area is located about 45 km east of Addis Ababa in the central highlands. The main agricultural production system in the district is mixed crop and livestock farming (Kahsay, 2004), which involves complementary interactions between crops and livestock, through the use of animal traction for crop production, manure for fertilization and crop residues for livestock feed (Powell *et al.,* 1993). The district is endowed with 6 crater lakes and 7 rivers (IPMS, 2004). Since the soils are predominantly vertisols, many seasonal swamp lands fill up with standing water for 6 to 8 months during the rainy season (Kahsay, 2004). All these water sources are used by people and livestock for drinking, recreation, waste disposal, rituals and spiritual celebrations as well as for irrigating vegetables (Sisay, 2007). The management of these water bodies is essential for the well-being and sustainability of the local ecosystems.

Water, like soil and air is one the environmental pathways that contribute to global pollution. In recent years, water utilization has increased and the amount of waste entering water bodies has also escalated due to many newly built factories, services and farms in the study district (Tesfaye, 2007). However, little or no treatment is done to municipal, farm and industrial wastes that enter lakes, rivers and swamps that are used as the main sources of drinking water for people and livestock (Tamiru *et al.,* 2005). During local rituals and liquor for celebrations, perfumes, animal proteins, and fats are thrown into lakes and rivers as sacrifices, which build up organic and chemical substances in the water bodies (Wakena, 2006). Washing of clothes, vehicles, horses and individuals on the edges of water bodies build up oil, dirt and detergents in the water bodies.

In contrast to the large body of knowledge related to crop-water interactions, research on livestock-water interactions remains in its infancy (Peden *et al.,* 2006). Therefore, this study was initiated to contribute to the body of knowledge by evaluating the role of livestock sector in water resource depletion and recharge under mixed crop and livestock production systems. This study also tried to determine water quality standards that meet livestock requirements. Moreover, the study provided an overview on the perception of the community about the sources of water pollution, adaptation and mitigation measures. Household interviews were used to document this information in addition to laboratory chemical analyses. This study is among the few that tried to examine the livestock and water interactions under smallholder mixed crop and livestock production systems in Ethiopia. It was also designed to highlight more research topics which will help to tailor specific policy and research options on livestock and water interactions.

7.2 The objectives

The objectives were:

- To identify the sources of water pollution.
- To assess the suitability of water bodies in the study area for livestock water uses.
- To assess the role of livestock in water depletion and recharge; and to suggest alternative means of reducing water pollution.

7.3 Materials and methods

7.3.1 The study area

The study area was located about 45 km east of Addis Ababa, at an elevation of 1600 to >2000 m above sea level. It is characterized as a semi-arid agro-climate and the main rain season occurs between June and September. In addition, the short rains occurred from March to April. The maximum mean annual rainfall is 839 mm. The minimum and maximum temperature recorded for the past 56 years (1953 to 2009) ranged from 8.0^{o}C to 28^{o}C, respectively. The mean annual temperature during the trial period was 18.5^{o}C.

All the lakes, rivers and swamps were being used as discharge points for chemicals from factories, farms, recreation, rituals and irrigation. All water bodies were open to human and livestock waste. They were surrounded by human settlements and for that reason surface water was usually contaminated with human waste (Wakena, 2006). This created severe public health problems. Water borne diseases such as typhoid, infectious hepatitis and infant diarrhoea were some of the epidemics that are common in the area due to water contamination (Wakena, 2006). Municipal and abattoir waste entered swamps that were used for grazing during the dry season. Some of the effluents from steel, detergent and plastic factories entered farm lands and permanent water ponds that were used for livestock watering.

7.3.2 Selection of water sampling sites

The selection of water sample sites along the water bodies and fluid waste courses were based on point and non-point sources for potential exposure to pollution by people and livestock. Point sources involved the discharge of substances directly from factories, sewage systems and flower farms since it was easy to identify and monitor. Sample sites under this category were Zekuala steel rolling factory, Oxford plastic package factory, East African detergent factory and flower farms located along the Wedecha River. The non-point sources were characterized as poorly defined entry points scattered over a large area. The major pollutants for non-point sources were agricultural runoffs with crop, animal and human waste. The sampling sites were designated from S1 to S14 as shown in **Table 7.1.**

Table 7.1: Type of water samples and the required analyses

Lab No:	Field name	Source	Descriptions
S1	Godino site dam water	Non-point	The water source was a dam constructed on hillside catchment. Farmers grew vegetables using chemical fertilizers and pesticides. Water was used by livestock.
S2	Mojo I River up stream	Point ource	The river was used for vegetable production in close proximity to flower farms. Drainage from flower farms ended in the river.
S3	Belbela pond	Point source	A small pond formed by water from a dam upstream. The pond was close to flower farms and was used by livestock. Drainage from flower farms entered the pond. The pond was also contaminated by livestock waste.
S4	Belbela River	Non-point	Spillover water from Belbela pond, which joined the Mojo River, about 1 km from the flower farms.
S5	Wedecha dam	Non-point	Water flowing directly from Wedecha dam which was near the flower farms.
S6	Keta Pond	Point source	A pond constructed by the community for livestock watering. The pond water was contaminated by Zekuala steel factory effluent and by livestock dung and urine.
S7	Zekuala steel rolling factory Pond	Point source	Effluent from Zekuala steel factory was directly channeled into the pond near a resident area. The pond was poorly fenced with barbed wire. Livestock, dogs, birds and children could enter and leave the site freely.
S8	Oxford factory chemical drainage	Point source	Plastic factory where effluent flowed into farms and the road side. The waste water was used by livestock and for washing cars and horses.
S19	East Africa chemical flow	Point source	Detergent factory where the effluent drained into farms.
S10	Hora Lake	Non-point	The lake was used for recreation, livestock watering, car and horse wash, laundry, and swimming. Annually, the lake was used for spiritual celebrations and foreign materials like perfumes, liquor, blood and animal products were poured into the lake.
S11	Mojo River down stream	Non-point	The river was used for livestock watering and for irrigation.
S12	Tap water	Non-point	Borehole water that was used for drinking and irrigation.
S13	Green Lake	Non-point	The lake had green-blue algae and was used by livestock watering during the wet season alone.
S14	Cheleleka swamp	Non-point	Municipal waste, runoff from farms, and abattoir waste entered the swamp.

7.3.3 Water sampling for physico-chemical analysis

Water sampling was done in May 2009. This period was strategically selected to coincide with the dry season before the on-set of the main wet season. That was the time of critical water shortage for livestock when they had to trek long distances in search of water and they were exposed to poor quality water. During the wet season livestock drank water at the homestead and nearby around grazing areas; or from pools of accumulated water from runoffs, temporary stagnant water and roadside water pools. Thus, the proposed suitable time to study the interrelation between water and livestock in terms of use, depletion and pollution was during the dry season.

The sampling procedure was based on the guidelines set for water sampling by the International Livestock Center for Africa by Tadesse *et al.* (1991). Water samples from factory waste water, lakes and rivers were taken from each site on 20 May 2009 between 08h00 and 11h00. Prior to sampling, 1-litre polyethylene bottles were cleaned by incubating them with 10% (v/v) nitric acid solution for 48 hours in a hot water bath and then by washing and rinsing them with distilled and de-ionized water. In addition, the bottles were thoroughly rinsed with clean water at the sampling sites before sampling.

The samples were collected directly from the outlets of the factories and from different sampling locations along rivers, lakes, swamps, ponds and ground water which were used by livestock. Samples were taken once during the study period with 6 subsamples from each point and then pooled and mixed thoroughly by hand shaking before the analysis. One litre of pooled water sample from each site was used for all chemical analyses.

Since rivers and out flows from the dam were less than 3 m deep, grab water samples were taken at livestock watering points. Six grab composite samples from lakes and swamps were taken at about 500 m apart based on visual observations at the proposed livestock drinking points. Samples from ponds were taken at livestock entry points. Ground water samples were collected after the pump had been running for 15 minutes in order to get representative water samples. Samples were transported to the Debrezeit Research Centre within 2 hrs of collection. All the procedures of water sampling were done as described by Tadesse *et al.*

(1991) in the guideline manuals for soil, plant, water, fertilizer, animal manure and compost laboratory analysis.

7.3.4 Secondary data

Secondary data from ILRI for 1997 to 2000 trials on runoff, infiltration and manure application were used to assess the effect of grazing intensity on water depletion, runoff, infiltration and its role on water recharge. This data was already used for several publications, but in this case we used this data to evaluate the effect of grazing intensity on water recharge and depletion and to highlight the role of manure in soil water retention. Dr Girma Tadesse was then the scientist at ILRI. He was kind enough to provide the raw data and publications for my use in this study, so that I could examine livestock and water relationships. The ILRI trial sites fell within the current study area.

7.3.5 Socio-economic survey

To complement chemical analyses with socio-economic status, a socio-economic survey was done to capture the perceptions of farmers about livestock and water interactions and water pollution. About 110 farmers were interviewed. They explained about water uses, sources of pollution as well as prevention measures used by the local community.

7.3.6 Physico-chemical data

A detailed waste water characterization was performed for selected parameters. Total N, P, K, Ca, Mg, Cl, CO_3 and HCO_3 were determined using Tadesse *et al.* (1991) water analysis guidelines. Total dissolved solids (TDS), conductivity and pH of the sampled water were also determined using the same guidelines.

7.3.7 Statistical analysis and mathematical calculations

SPSS Statistical package version 17.0.1 (2008) was used for univariate analysis, statistical tests and comparisons. Crop coefficients (Kc) were used with ET_0 to estimate specific crop evapo-transpiration rates (FAO, 1998). Crop coefficient is a dimensionless number (usually between 0.1 and 1.2) that is multiplied by the ET_0o value to arrive at a crop ET value or ETc.

Thus; $ETc = ET_0 \times Kc$

Where; ETc = Specific crop evapo-transpiration (mm)

ET_0 = Reference crop evapo-transpiration rate (mm) at a specific location

Kc = Crop coefficient

The resulting ETc can be used for irrigation scheduling and to programme when irrigation should occur and/or how much water should be added into the soil.

7.4 Results and discussion

7.4.1 National water resources potential

The annual renewable fresh water resources in Ethiopia amount to some 122 billion m^3 per year in the twelve river basins, but only 3% remains in the country, while 97% is lost in runoffs to the lowlands of neighboring countries (Awulachew *et al.,* 2005). There is also an estimated potential of 2.6 billion m^3 of ground water (MoWR, 2002). In 1990, the amount of water per capita per year was estimated at 2 620 m^3 for a population of 47 million people. In 2003 based on a population of 68 million people, the per capita share of water was 1794 m^3/year. However, by 2005 this potential had been reduced to 1 707 m^3 due to population growth to about 73 million people. According to FAO (2006), the per capita water status of Ethiopia changed from a water sufficient country in the 1990s to a water scarcity country in 2005.

Awulachew *et al.* (2005) projected that Ethiopia will become a physically water scarce country by 2020 when per capital water share will have been reduced to 1000 m^3/ per capita/ year as shown on **Figure 7.1.** This will put the country on the threshold of being classified as water scarce country with less than 1000 m^3/ per capita/year (Rosegrant *et al.,* 2002).

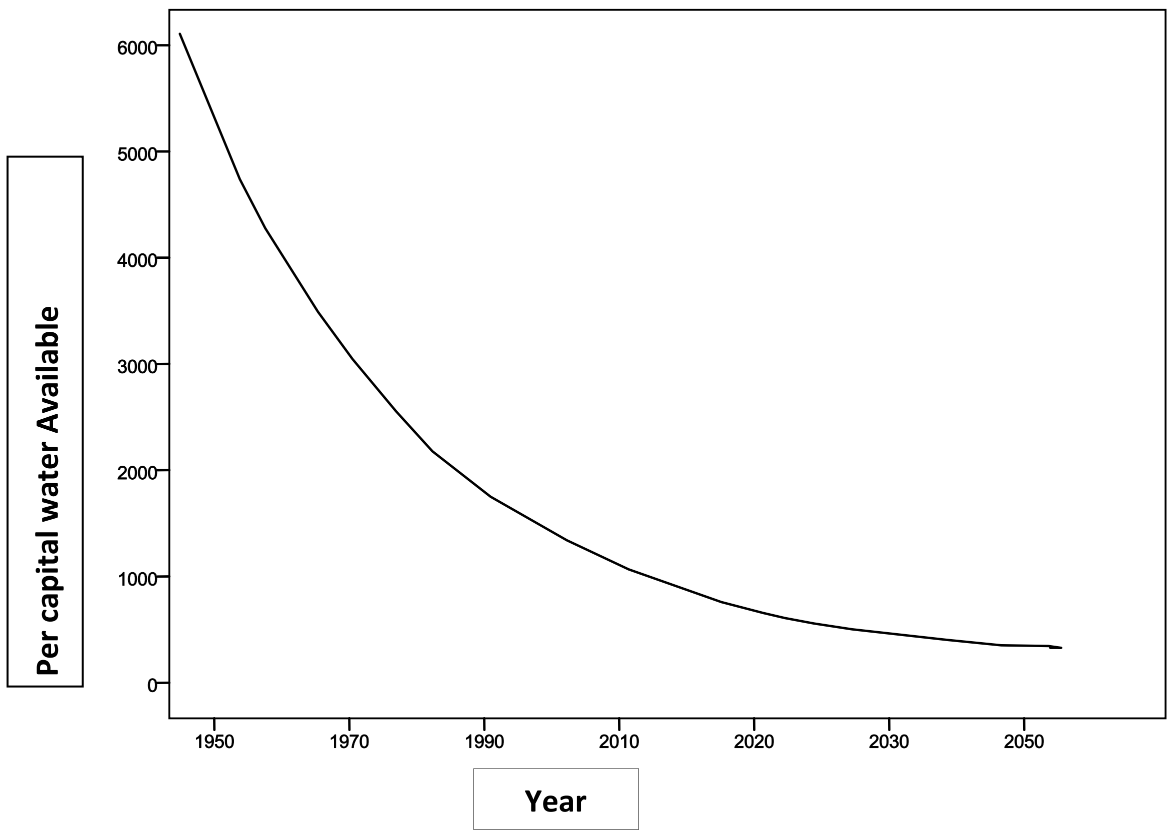

Figure 7.1: Projected water availability per capita per year from 1950 to 2050
Source: Wulachew *et al.* (2005)

At this stage of water development, where the country withdraws less than 5% of its fresh water resources form rivers, lakes and ground water, labeling the country as a water stress zone may not be so justifiable (MoWR, 2001). The country has a good amount of water resources, but the current clean water supply is only about 34% (MoFED, 2011). The distribution and quality of available potable water is uneven over the country where the lowlands and drought-prone areas have much less water than the highlands and plateau areas of the country.

On the other hand, the decline in rainfall amounts from June to September in the past three decades was estimated to be about 14% less rain than the normal (MoWR, 2001). This has been witnessed by the decline in rainfall amount in the north central Ethiopian Highlands from time to time. MoWR (2001) estimated a decline of 8% and 18% in annual precipitation between 1945 and 1964, respectively, and an increase in runoff within the same range. The decline in precipitation showed that the future potential for more rain water harvest is at a risk. Increased runoff contributed to soil losses and a decline in infiltration rate which would have negative consequences on crop water requirements and yield (Haile Sellassie *et al.,* 2006; Peden *et al.,* 2007). It was estimated that about 1900 million tons of soil is eroded annually from the highlands (MoWR, 2001). This is equivalent to an average of 35 tons of soil per year that is lost from every hectare of land in the highlands.

The major contributing factors to the decline in water resources are combined pressure of human and animal population on natural resources that led to excessive deforestation, loss of biological diversity, overgrazing, soil degradation and various forms of pollution and contamination (Tesfaye, 2007). The global climate change also contributed to the decline in water resources due to global warming and a decrease in annual precipitation (IPCC, 2007). Economic growth and urbanization increased the demand for milk and meat which also fueled the demand for additional water for livestock (Delgado, 1999). The demand for milk and meat is expected to double in the next 20 years at a rate of between 2.5 to 4% per annum (IPCC, 2007). This issue has raised concern on water management to meet human and livestock requirement and taking into account the future population growth and economic development.

7.4.2 Livestock water intake

Water is the most common molecule in a living body, which forms 60 to 70% of the body weight. Deprivation of water can quickly result in the loss of appetite and weight; and it becomes critical when an animal loses between 15 and 30% of its body weight (FAO, 2006). Water is vital for all physiological functions such as homeostasis, digestion, metabolism of protein, fat and carbohydrates, lubrication of joints, cushioning of nervous system, transmission of sound and eye sight; and excretion of body waste (NRC, 1981; Luke, 1987; FAO, 2006). The minimum livestock water requirement is influenced by normal growth, fetal growth, lactation and the replacement of water that is lost by excretion, sweat and evaporation from the lungs and skin (NRC, 1981; NRC, 2000; NRC, 2001). In general, livestock water requirement is influenced by the rate and composition of weight gain, pregnancy, lactation, activity, productivity, type of diet, feed intake and environmental temperature, humidity, wind, etc. (NRC, 1981) as shown in **Table 7.2**.

Water intake is also influenced by the type of species and breed of livestock, for example Zebu cattle has a lower intake of water than exotic cattle breeds (Jahnke, 1982). It is estimated that water intake per kilogram of dry matter intake may be as much as 40% less for sheep than cattle. This might be partly due to species ability to conserve water and for physiological differences among species, such as camels and small ruminants. Water intake also varies between species, breeds and individual animals (FAO, 2006). The sources of water for livestock are direct water consumption, water in feeds and metabolic water (NRC, 1981; Peden *et al.,* 2006). Water intake in feeds and forages plus that which is consumed *ad libitum* as free water is approximately equivalent to the water requirement for livestock.

Watering frequency has a significant impact on the performance of livestock, especially those in the arid and semi-arid areas where animals are usually watered less frequently (Jahnke, 1982). A study conducted using local goats in Ethiopia revealed that goats which were watered once every four days spent more time in the shade on day 2, 3 and 4 compared with those watered every day (Mengistu, 2007). Drinking of water every fourth day affected both behavioral and thermoregulatory mechanisms in goats, and hence to avoid water loss they had to use the available water more efficiently (Mengistu, 2007). In addition, body weight gain was lower in goats that were watered every four days than in those that had access to drinking water daily. This suggested that shortening of watering intervals improved the growth potential and productivity of goats.

Mengistu (2007) reported that under extensive grazing conditions during the dry season, the weight and condition of lactating cows declined more rapidly when they were watered every 3 days than those that were watered daily. However, when water intake was adjusted to a constant body weight and dry matter intake, the species differences were negligible (NRC, 1981).

Since feeds contain some moisture and the oxidation of certain nutrients in feeds produce metabolic water, not all the required water must be provided by drinking (ILCA, 1994; Zinash *et al.,* 2003). The moisture content in feeds is variable from 5% to 90% (Jutzi *et al.,* 1987). Silage, green chopped and growing forage are usually very high in moisture content, while grains, hay and dormant pasture are low in moisture.

Table 7.2: Livestock water intake by species under different ambient temperatures

Species	Physiological condition	Average Wt. (kg)	Water requirements litres/animal/day		
			15°C	25°C	35°C
Cattle	Pastoral system lactating cows (2 litres/day)	200	21.8	25	28.7
	Large breed dry cows(279 days pregnancy)	680	44.1	73.2	102.3
	Large breed mid lactation (>30 litres /day)	680	102.8	114.8	126.8
Goat	Lactating does (0.2 litres /day)	27	7.6	9.6	11.9
Sheep	Lactating ewes (0.4 litres /day)	36	8.7	12.9	20.1
Camel	Mid lactation (4.5 litres /day)	350	31.5	41.8	52.2
Chicken	Adult broilers (100 birds)	-	17.7	33.1	62
	Layers (100 birds)	-	13.2	25.8	50.5
Swine	Lactating sows(weight gain 200 g/day)	175	17.2	28.3	46.7

Source: FAO (2006)

High energy feeds produce more metabolic water than low energy feeds. Thus, poor quality rations require more drinking water than high quality feeds. These are obvious complications in the assessment of water requirements by smallholder farmers. Fasting cattle or those fed low protein diets may get water from the metabolism of body protein or fat, which is 1% of body weight or 3.1 kg/cow (ILRI, 2002).

In 2010, the livestock population in Ethiopia was estimated at 53.4 million cattle, 48.3 million shoats, 8.1 million equines and 1.1 million camels (FAOSTATA, 2012). This was equivalent to 50.4 million tropical livestock units (TLU). A TLU is equivalent to an animal that has 250 kg live weight on maintenance ration. Assuming an average water consumption of 25 litres/day/TLU (Jahnke, 1982), the estimated daily water consumption was about 1.25 million m^3 per day. This added up to about 456.6 million m^3 per annum. This requirement is expected to increase due to the increase in livestock population and the envisaged improvement in productivity in the future. Improvements in the dairy sector, for example, will require additional water for milk production and sanitation.

According to Jahnke (1981) the amount of water intake for livestock was close to 12.81 m^3/TLU/year and a total of 82.5 m^3 per household per annum at an average ambient temperature of 15°C **(Table 7.3).** With increased ambient temperature from 15 °C to 25°C, the annual water requirement increased to15.2 m^3/TLU/year, which was 19% more water for 10°C change in temperature. At 35°C, the annual water requirement increased by 42% compared with the water requirement at 15°C **(Table 7.3).** At high temperature water consumption increases by 2.1% for each °C increase in temperature. Therefore, with global warming the increase in temperature will increase livestock water requirement as well.

Based on the current study the average family size in the study site was estimated at 6.1 people, and the potential available water per capita per annum in 2009 was 1640 m^3 (Awulachew *et al.,* 2005). The available water per household per year was estimated at 10 000 m^3 (1640 m^3/per capita/year x 6.1 people/household). The number of livestock owned per household was estimated at 6.44 TLU. At 15°C ambient temperature annual water requirement for livestock in one household was expected to be 82.5 m^3 as shown in Table 7.3 or 0.8% of total water available per household per annum. At the 35°C ambient temperature the water demand by livestock increased by 42.5% or shared only 1.2% of total available water per household per year. This indicated that the amount of livestock water was insignificant in the water resource depletion or livestock drinking water was not the main concern.

Table 7.3: Livestock water requirement per household in the study area

Species	Average number of animals per household	TLU conversion factor	TLU	Total water requirement per day (L)		
				15°C	25°C	35°C
Cattle	6.57	0.75	4.92	143.2	164.3	188.6
Sheep	2.01	0.1	0.201	17.5	25.9	40.4
Goats	2.28	0.1	0.228	17.3	21.9	27.1
Chicken	7.57	0	0	1.0	2.0	3.8
Equines	2.16	0.5	1.08	47.1	54.0	62.0
Total	**-**	**-**	**6.44**	**226.1**	**268.1**	**321.9**

TLU conversion factor based on Jahnke (1982)

7.4.3 Crop residue and water depletion

Water depletion by livestock includes drinking water and waste management (FAO, 2006), sedimentation of water bodies by trampling and overgrazing that contributes to surface runoff (de Hann *et al.,* 1997); and water that is used for feed production (Mekete, 2008). Some researchers have made attempts to quantify livestock water depletion on a global and regional level (FAO, 2006). Water depletion at regional and national levels was estimated by Peden *et al.* (2006), while Mekete (2008) estimated water depletion at national and household levels. These estimates had differences, because some of the workers did not consider water depleted by crop residues in their estimation of water depletion by livestock.

Tibebu (2007) and Mekete (2008) tried to quantify water drained by crop residues during normal plant growth as water depleted by livestock. More scientific evidence was required to justify the inclusion of water drawn by crop residues as water depleted by livestock because the proportion of crop residues that are directly consumed by livestock was not quantified accurately. In addition, residues lost to non-farm uses, leaching, evaporation and off farm transit have to be documented precisely (Peden *et al.,* 2007). Moisture retained by crop residues was calculated based on grain to residue ratio, taking into account the amount of water consumed by the total crop biomass (Mekete, 2008), without explaining the variation in moisture based on soil type, plant physiology, plant part and water lost to the environment (FAO, 1998).

Therefore, livestock water depletion through the consumption of crop residues needs further investigation because it affects the efficiency of water resource use by livestock in mixed farming (Haile Sellassie *et al.,* 2006; Peden *et al.,* 2006). It is also important to note that, livestock help to sustain water resources in ecosystems by using the little available water in crop residues and through metabolic water recharge through the oxidation of feeds (Peden *et al.,* 2006; ILRI, 2002). The water recharged through the feeding on crop residues reduces the loss of water through evapo-transpiration, volatilization and trampling.

About 12 million tons of crop residues are produced annually from 6 million hectares of land cultivated in Ethiopia, with the assumption that the ratio of straw to grain is 2:1 (Kahsay 2004). Out of these crop residues, one-third is left in the field for grazing (FAO, 2006). In mixed crop and livestock production systems, livestock is mostly fed on crop residues, which are by products that did not require additional water to handle (Peden *et al.,* 2006; Tibebu, 2007; Mekete 2008). Since efforts to improve crop water productivity were focused on grains and fruits that people consume, any residues and by-products that can be used by animals represent potential feed sources that require no additional water loss through evapo-transpiration. Thus animal production from crop residues can take advantage of these feed sources, with the possibility of huge gains in livestock water productivity (Peden *et al.,* 2006). Livestock water productivity for a group of farmers was positively correlated with the share of crop residues in animal diets. Therefore, use of crop residues can boost farm incomes without the use of additional water.

The amount of water required to compensate the evapo-transpiration loss from the cropped fields is defined as crop water requirement (FAO, 1998). Although the values for crop evapo-transpiration and crop water requirement are related, crop water requirement refers to the amount of water that needs to be supplied, while crop evapo-transpiration refers to the amount of water that is lost through evapo-transpiration. The average ET_0 for the study area was 3.55 mm/day (Wakena, 2006). Average Kc for Teff was 0.6125, and for the 105 growing days the total ETc was 253.7 mm (Tibebeu, 2007; Mekete, 2008). In similar reports the average Kc for wheat was 0.772 with a total ETc for 130 growing days of 324.4 mm. Average Kc for pulses was 0.73 for 110 days and the total ETc was 300.5 mm (Wakena, 2006; Tibebu, 2007; Mekete, 2008). Average Kc for pasture was 0.87 for 365 growing days and the total Etc was estimated at 1147.67 mm (Tibebeu, 2007; Mekete, 2008), with a deficit of 614.6 mm, because the effective rain per annum in the study area was 662.6 mm (Wakena, 2006). These results showed that, except for grasses the annual rainfall was enough to grow cereal grains that could be used as crop residues for livestock feed.

If livestock production were to be based solely on the use of crop residues and other by-products, water for animal feed production would be reduced (Peden *et al.,* 2006). However, this extreme may not be economically and environmentally desirable if sufficient residues and manure were not returned to the soil to maintain soil productivity (Stangel, 1993). The limiting factors to the use of crop residues as livestock feed are poor voluntary feed intake and low digestibility of residues. In order to improve the nutritional availability of crop residues, various methods of physical and chemical treatments have been developed (FAO, 2006). Both types of methods have been found to require heavy investments on machinery and regular supply of replacement parts and chemicals which would not be economical for smallholder farmers. Growing of fodder legumes and the use of fodders as supplements to crop residues is the most practical and cost-effective method of improving the nutritional value of crop residues (Alemayehu, 1985). Better uses of crop residues have to be stressed and research efforts must be directed to developing methods of increasing the utilization of these resources (FAO, 2006)

7.4.4 Grazing intensity and water depletion

Mwendera and Mohamed Saleem (1997) reported that with increasing slope and grazing intensity, infiltration rate declines and soil losses increase significantly. They indicated that on ploughed and heavily over grazed land the infiltration rate was 2.4 mm/hr and soil loss was 1.6 t/ha at 0 to 4% slope; compared to the infiltration rate of 6.1 mm/hr and soil loss of 1.8 t/ha at 4 to 8% slope. Comparatively, for ungrazed or fallow land (control) water infiltration rate was 17.6 mm/hr and soil loss of 0.2 t/ha at 0 to 4% slope; and 13.4 mm/hr for 4 to 8% slope with soil loss of 0.5 t/ha. The results of the two plots indicated that overgrazing reduced water infiltration by 8 times and soil losses by 3 times compared to ungrazed land mainly due to better vegetation cover on ungrazed land.

A millimetre of rain falling on one square metre produces one litre of water. An annual rainfall of 880 mm in the study area produced 880 L/m^2 (880 x 10,000 = 8 800 000 L or 8 800 m^3/ha) which is about 13 200 m^3 per household. The runoff rate or the water loss from different plots varies based on whether the land is grazed or ungrazed, ploughed or not and the slope (Mwendera and Mohamed Saleem, 1997). **Table 7.4** shows secondary data obtained from Dr Girma Tadesse. The runoff is higher for grazed plots than ungrazed plots, for example in 1999 a ploughed grazing plot (PLG) had 1.93 mm runoff compared to 0.97 mm runoff from ungrazed plot (NOG). Results showed a 100% difference in runoff between the two plots.

Wakena (2006) reported a runoff coefficient of 0.32 for the study area or 285.4 mm runoff. This figure could double if the intensity of grazing continued to a level of 570.88 mm runoff or a runoff coefficient of 64%. The estimated runoff was quantified as 10 m^3/ha or 15

m^3/household. Assuming 1 ha of land has a surface area of 10 000 m^2 and 1 mm is equal to 0.001 m, which is a loss of 1 mm of water this equals to a loss of 10 m^3 of water per hectare. In other words, 1 mm/day^{-}is equivalent to 10 m^3/ha/day. Therefore, overgrazing, ploughing and grazing have to be given due consideration in order to reduce runoff to prevent the loss of soil nutrients and decreased soil productivity as a result of poor moisture retention.

Table 7.4: Runoff and infiltration rate due to different grazing intensity and slopes

Treatment	1999						2000			
	Runoff (mm)		**Infiltration rate (mm)**		**Rainfall (mm)**		**Runoff (mm)**		**Infiltration rate (mm)**	
	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
MDG	2.94	2.58	26.9	73.7	17.11	18.34	14.38	3.03	5.43	5.20
NOG	0.97	0.72	48.5	63.9	20.00	23.24	2.29	4.70	6.79	6.50
LTG	1.81	1.82	40.2	65.6	18.29	19.23	9.79	3.64	4.24	4.45
HVG	1.70	1.93	24.8	28.8	17.03	19.68	5.28	2.75	3.56	7.08
PLG	1.93	1.83	25.4	25.4	17.56	17.71	4.98	4.94	6.36	7.10

Key: MDG = Medium Grazing; NOG = No Grazing; LTG = Light Grazing; HVG = Heavy Grazing PLG = Ploughed and Grazing. **Source:** Secondary data from Tadesse (2000)

7.4.5 Livestock water depletion to meet animal protein demand

The major influences on water intake in cattle are dry matter intake, environmental temperature, stage and type of production (NRC, 2000). Global temperature increases by 0.2°C per decade (SRES, 2000). Accordingly, by 2020 the global average maximum temperature is expected to rise by 0.4°C compared to the year 2000 and the precipitation is expected to drop by 10 to 20% in most areas (IPCC, 2007). Assuming similar dry matter intake and dietary salt consumption in 2020, beef cattle water requirement per kg of meat produced would increase by 1% (NRC, 2000). From this figures, it is clear that the increase in total water demand would be very high when multiplied by the total meat demand at that time.

The world meat demand in 2020 is projected to be 334 million metric tons/annum, if the consumption is estimated at about 45 kg/capita/year (Peden *et al.,* 2007) because the world consumption of animal products is assumed to be growing. Consumption and production are rising at about 2.5% to 4% a year in developing countries, but at less than 0.5% a year in developed countries (Peden *et al.,* 2007). The rising demand and consumption are closely linked to the increasing purchasing power due to rapid urbanization, population growth and economic prosperity. The projected milk demand in 2020 is estimated to be 660 million metric tons or 89 L/capita/annum (Peden *et al.,* 2007). The protein water productivity of milk is estimated at 40 g/m^3 of water (Renault and Wallender, 2000). To meet the milk demand in 2020 the water intake per 40 g of milk protein will increase by 10 L with the rising global temperature.

Renault and Wallender (2000) estimated beef cattle protein to water productivity at 10 g/m^3 of water. Mekete (2008) calculated meat water productivity of livestock under different farming systems in the Ethiopian highlands to be in the range of 1.89 to 3.09 g/m^3 of water with an average value of 2.65 g/m^3 of water. The lower value of meat to one unit of water was due to minimum livestock off-take rates in the highlands. Therefore, people in mixed crop and livestock production systems in the Ethiopian highlands should have 16 981 m^3 water per capita to attain the meat demand by then (45 kg/capita/year), which is 250% higher than the present meat consumption. Awulachew *et al.* (2005) noted that the available water per capita in 2020 will be less than 1000 m^3/capita. Thus, alternative water management mechanisms such as water recycling, effective water conservation programmes and comprehensive family planning to control population growth have to be sought. The suggested water management mechanisms have to be integrated in the planning and implementation of water resource utilization and to ensure community participation.

Mekete (2008) estimated that it required 1 m^3 of water to produce 0.05 L of milk from Zebu cattle in northern Ethiopia. Therefore, to meet the targeted 2020 per capita milk consumption of 89 L/ annum, it will require 1 790 m^3 of water which again is far higher than the projected water availability per capita in 2020 that was estimated at less than 1 000 m^3/per capita. This suggested that there is a need to have livestock breeds with higher milk productivity and efficient milk-water productivity ratio. It will also require the implementation of strategies for water conservation, water recycling and family planning to meet the milk demand of the ever increasing human population. In general, the issues of water and livestock relationships become critical when an attempt is made to increase animal protein to meet protein demand under both extensive and intensive agriculture.

7.4.6 Livestock water recharge

A study conducted at ILRI in Debrezeit Research Station on Boran x Friesian crosses showed that the mean amount of metabolic water reported was 3.1 kg/cow/day (ILCA, 1992). Water turnover including water intake and metabolic water was lower in early lactation (52.3 L) than in late lactation (57.1 L). The proportion of total water excreted through dung, urine and milk was 38.0, 17.0 and 13.8% in early lactation, and 45.0, 19.3 and 8.2% in late lactation, respectively (ILRI, 2002). At smallholder level, local cattle drink 25 L of water per day (Jahnke, 1982), and by extrapolating the average proportion of water excreted in early and late lactation, the water excreted from local cows through dung, urine and milk would be 10.4 L, 4.5 L and 2.8 L, respectively. This estimates the amount of water lost from a cow's body at 17.7 L/day/TLU or 71% of drinking water returned to the environment through livestock recharge.

Peden *et al.* (2007) suggested that the drinking of water is not a water depleting process because the water remains in the domain. This was in agreement with Haile Sellassie *et al.* (2007) who reported that livestock drinking water amounts to less than 2% of the total water utilized and degraded by livestock and is of little importance in terms of volume of water flow. Livestock also contribute to water recharge when manure is used in the field by increasing the soil water retention capacity (Tesfaye *et al.,* 2004). Manure increases soil moisture content by 10% both under medium and heavy grazing conditions (Murwira *et al.,* 1995). Therefore, livestock has a positive water balance in the ecosystem when manure is used as fertilizer. From field experimental data conducted by ILRI (2000) water retention ability of the soil in ungrazed land, medium and heavy grazed land per household reported are shown in **Table 7.5.** Under medium grazing without manure, soil moisture per kg of soil was estimated at 170 mm while manure increased soil moisture to 190 mm, which was an increase of 11% in moisture content. This meant that manure improved infiltration rate by 11% or compensated the losses induced by grazing.

Table 7.5: Effect of grazing pressure on soil moisture

Month	No grazing - soil moisture (mm.kg^{-1})	Medium grazing - soil moisture (mm.kg^{-1})		Heavy grazing - soil moisture (mm.kg^{-1})	
		Manure	No manure	Manure	No manure
Feb	0.14	0.11	0.10	0.08	0.07
May	0.16	0.14	0.14	0.12	0.12
Jun	0.16	0.15	0.13	0.14	0.15
Jul	0.29	0.29	0.27	0.26	0.22
Sep	0.36	0.33	0.28	0.3	0.26
Oct	0.2	0.17	0.16	0.16	0.12
Dec	0.14	0.13	0.15	0.11	0.13
Average	0.207	0.189	0.17	0.167	0.153

Source: ILRI (2000) based on experiment results in Debrezeit Research Station

The average land ownership per household in the study area was 1.32 ha of which only 0.1 ha benefited from manure fertilization, and this was insignificant. However, under agricultural systems where manure was used widely, soil moisture retention improved the yield and productivity. Wakena (2006) estimated the surface runoff of 285.4 generated from the annual mean rainfall of 887.03 mm with the average annual rainfall-runoff coefficient of 0.32 for the years ranging from 1995 to 2003. Based on this assumption, manure application could improve water retention by 11% or retains 31.4 mm of moisture and limit the surface runoff to 254 mm.

7.4.7 Livestock and safe water

According to the economic growth and transformation plan (MoFED, 2011), only 38% of households in the country use safe sources of water. In the current study, only 56% of the respondents said that they use safe water sources, which is better than the national average. About 87% of the respondents identified livestock as the main cause of water sedimentation and pollution through the addition of sediments, dung and urine in the water as shown on **Table 7.6**. The effect of livestock is highest on standing water sources such as lakes, ponds and swamps, and less in rivers. About 90% of the respondents ranked livestock influence on water quality highest, particularly on standing water than on rivers. Water sources were situated in less than 1 km distance from 64% of the respondents, while 36% were more than 1 km away from water sources. The distance from water source has an impact on women who are traditionally obliged to walk for several hours to fetch water for household use. Respondents reported that livestock milk production and weight decreased significantly during long dry periods due to poor water quality and trekking for long distances in search of water.

Table 7.6: Pollutants of water sources

Source of water pollution	Proportion of respondents (%)
Animal droppings (dung and urine)	87.7
Animal trampling in water	77.5
Plant decays and weeds in water	63.8
Agri-chemical from flower farms	21.4
Accumulation of dust by wind	11.3
Agro-chemicals from smallholder farms	1.80

7.4.8 Interpretation of water physico-chemical analysis for livestock use

Water quality is important in maintaining water consumption by livestock. Physico-chemical factors such as pH, total dissolved solids, hardness, total dissolved oxygen, organoleptic properties (odor and taste), chemical compounds in excess (NO_3, Fe, Na, SO_4, and Fl), toxic compounds (As, HCN, Pb, Hg, hydrocarbons, organo-chlorides), organophosphates and bacteria; were criteria for the evaluation of drinking water quality for people and livestock. However, the following measurements were critical when considering whether the water was suitable for livestock: pH, salinity, EC, Cl and NO_3 level (David, 2009). **Table 7.7** shows the range and limits that were used as standards for the interpretation of the suitability analysis of water in USA and Canada (Canadian Water Quality Guidelines, 1987; EPA, 2004). These standards were used in the current study for the interpretation of water quality. This assessment focused on how safe a water source was for people and livestock in the study area. The results of the physico-chemical composition analyses are indicated in **Tables 7.9 and 7.10.**

Table 7.7: Water quality guidelines

Element	Desired upper limits (ppm)	Maximum upper limit (ppm)
Aluminum.	5	10
Arsenic	0.2	0.2
Bicarbonate	Unknown	<1000
Boron	5	30
Cadmium	0.01	0.05
Calcium	100	150
Chloride	100	300
Chromium	1	1
Cobalt	1	1
Copper	0.2	0.5
Fluoride	2	2
Lead	0.05	0.1
Magnesium	50	100
Manganese	0.05	0.5
Mercury	0.01	0.01
Nickel	0.25	1
Selenium	0.05	0.10
Sodium	50	300
Sulfate (S from SO_4)	20	100
Sulfate (SO_4)	50	300
Vanadium	0	0.1
Zinc	25	50
Nitrate (NO_3) ppm	45	130
Nitrate (NO_3-N) N from NO_3	10	20
Total dissolved solids	**960**	**5000**

Source: CCREM (1987); US Environmental Protection Agency (EPA, 2004)

The reviews on water physico-chemical content detailed below were based on the information obtained from the USA Environmental Protection Agency (2004), CCREM (1987) and the National Research Council (1974).

7.4.8.1 pH

Water for domestic and stock use should have a pH range of 6.5 to 8.5 (David, 2009). The water pH denotes the alkalinity or acidity of a substance. A pH of 7 is neutral, while >7 indicates alkalinity and <7 indicates acidity. The following water sources from the current study area exhibited high pH values above 8.5: Zekuala Steel rolling and metal plant effluent discharge point (9.85), East Africa detergent factory effluent discharge point (8.93), Hora Creator Lake (9.30) and Green Lake (9.94) as shown in **Table 7.9.** All the water sources were accessible to livestock all year round, except Green Lake which was accessed during the wet season. High pH values tended to facilitate the solubilization of ammonia, heavy metals and salts (Christensen *et al.,* 1996). Lethal effects of pH on aquatic life occurred when the pH was <4.5 and or >9.5 (David, 2009). In the current study, the anthropogenic factors which contributed to high pH were people mismanagement of the water bodies and industrial effluents. Highly alkaline water >9.0, like the Green Lake was also reported to cause digestive upsets and diarrhoea, lower feed conversion efficiency and reduce intake of water and feed (Pond *et al.,* 2005).

7.4.8.2 Salinity

Salinity is the sum of all mineral salts present in the water, including Na, Ca, Mg, Cl, SO_4 and CO_3. Total dissolved solids and total soluble salts are indicators of salinity and are also physico-chemical properties that are used to assess water quality (Christensen *et al.,* 1996). These terms are used synonymously to measure the amount of total inorganic matter dissolved in water which includes: Na, Cl, HCO_3, SO_4, Ca, Mg, Si, Fe, NO_3, Sr, K, CO_3, P, Bo and Fl in water (Christensen *et al.,* 1996). Although total dissolved solids denote the sum of inorganic minerals in the water, the actual mineral composition of the total dissolved solids in water may be quite different (Christensen *et al.,* 1996). Saline or NaCl in the water is one of the most common causes of high total dissolved solids in water. However, the effect of excess NaCl on water intake and animal performance is less than when the combined effect of excess SO_4, Mg and/or Na were considered (Christensen *et al.,* 1996).

Research to determine the effects of total dissolved solids on the performance of lactating dairy cattle produced varying results on water intake, feed intake and milk production (Olkowski, 2009). When total dissolved solids level in the water was < 3 000 ppm, there was little or no effect on cattle, although at first there were temporary or mild cases of diarrhoea (Olkowski, 2009). The salinity level of water in the study area was moderate, between 1500 and 3580 ppm, which was considered safe in terms of the guidelines of CCREM (1987) and EPA (2004) as shown on **Table 7.8.** The effects of salinity on milk production and animal performance were variable when total dissolved solids were 3 000 to 5 000 ppm. However, high total dissolved solids in water were more likely to decrease milk production during summer months than in winter months (Olkowski, 2009). The guidelines suggested that water containing < 5 000 ppm of total dissolved solids is acceptable for lactating cattle, but water containing > 7 000 ppm is not acceptable for all cattle (NRC, 2001) as shown in **Table 7.8.** The effect of salinity on livestock health and productivity depends on species, breed and age of the animals, the mineral content of the feed, temperature (ambient and water temperature) and the type of minerals present in the water (Christensen *et al.,* 1996).

Table 7.8: Guidelines to saline water use

Total dissolved solids	
< 1000 ppm (fresh water)	Presents no serious burden to livestock.
1000 - 2999 ppm (slightly saline)	Should not affect health or performance but may cause temporary mild diarrhea.
3000 - 4999 ppm (moderately saline)	Generally satisfactory, but may cause diarrhoea, especially on initial consumption.
5000 - 6999 ppm (saline)	Can be used for reasonable safety for adult ruminants but should be avoided for pregnant cattle and calves.
7000 - 10000 ppm (very saline)	Should be avoided if possible. Pregnant, lactating, stressed or young animals can be affected.
> 10000 ppm (brine)	Unsafe, should not be used under any conditions.

Source: CCREM (1987); US Environmental Protection Agency (EPA, 2004)

7.4.8.3 Specific conductivity

Specific conductivity is the ability of water to conduct electricity. The greater the number of ions in the water, the more current the water can conduct. Conductivity is expressed in terms of microsiemens per centimetre (µS/cm). Natural water has a conductivity of between 50 and 1500 µS/cm. Coastal streams have specific conductivity value of 100 µS/cm, while interior streams have up to 500 µS/cm (NRC, 1981). According to Olkowski (2009) approved and working guidance such as of EPA (2004) and CCREM (1984) determined acceptable levels of electric conductivity for livestock, irrigation, industrial and potable water. In the current study high conductivity was found in eight sample sites estimated at above EC 4000 µS/cm. The high conductivity value indicated that the water sources in the study area had a high concentration of mineral ions, which varied between 50 and 1500 µS/cm as shown on **Table 7.9.**

7.4.8.4 Carbon and total inorganic carbon

This is the sum of CO_3, HCO_3 and H_2CO_3. The relative amount of each of these three components is dependent on the pH of the water. At pH 7 to 8, which is typically found in fresh water systems, the HCO_3 ions dominate (60 to 90% of the total inorganic carbon). HCO_3 concentration in surface water is usually less than 500 mg/L and frequently less than 25 mg/L (NAS, 1974). C is a nutrient required by some biological processes, while inorganic forms of C are part of the C cycle in the biosphere. HCO_3 ions serve as the main buffer in fresh water systems and provide CO_2 for photosynthesis (NRC, 1981). Many industries use HCO_3 salts because of their high solubility. In the current study, the concentration level of CO_3 and HCO_3 were below 500 mg/l except for the two lakes (Green and Hora), most of the sample sites had normal CO_3 content as shown in **Table 7.9.**

Table 7.9: Chemical composition of water in the study area

	Sample site	pH	EC (μS/cm)	TDS (ppm)	CO_3 (mg/L)	HCO_3 (mg/L)	N (mg/L)	NO_3 (ppm)
1	Godino dam	7.72	4600	2940	48	170.8	190.0	841.7
2	Mojo River I	8.1	4440	2840	24	219.6	690.0	3056.7
3	Belbela pond I	7.46	3040	1940	24	146.4	260.0	1151.8
4	Belbela River II	7.82	2590	1660	24	146.4	660.0	2923.8
5	Wedecha dam	7.72	4160	2660	48	170.8	500.0	2215
6	Keta pond	7.28	3610	2310	36	109.8	250.0	1107.5
7	Zekuala steel factory pond	9.85	3950	2530	168	36.6	190.0	841.7
8	Oxford factory chemical discharge	7.69	4150	2660	48	207.4	380.0	1683.4
9	East African chemical flow	8.93	4020	2570	180	402.6	370.0	1639.1
10	Hora Lake	9.03	2340	1500	300	829.6	380.0	1683.4
11	Mojo River II	8.09	4950	3170	48	378.2	610.0	2702.3
12	Tap water	7.50	4080	2610	72	231.8	540.0	2392.2
13	Green Lake	9.94	5600	3580	1200	707.6	180.0	797.4
14	Cheleleka swamp	7.18	2150	1380	-	160.0	340.0	1506.2

7.4.8.5 Nitrates

Cattle performance and reproduction are affected by nitrates in the water. Toxicity occurs when NO_3 is reduced to NO_2 (Costa *et al.,* 2002). NO_3 level in water in excess of 0.3 mg or NO_3-N/L contributes to excessive algae growth in water (Olkowski, 2009). **Table 7.10** shows a guideline to levels of NO_3 and NO_3-N and precautions to be taken in the use of water for livestock and poultry (EPA, 2004; CCREM, 1987). Drinking water, especially from surface or shallow ground water, may become contaminated with high levels of NO_3. A slight decline in reproductive performance was reported in herds where NO_3-N levels were >20 ppm (Olkowski, 2009). However, concentrations of <10 ppm NO_3-N or 44 ppm of NO_3 in water are considered safe for dairy cattle (NRC, 2001).

Table 7.10: Guidelines for nitrate level in water

Nitrate (ppm)	Nitrate -Nitrogen (NO_3-N) (ppm)	
0 - 44	0 - 10	No harmful effects.
45 - 132	10 - 20	Safe if diet is low in nitrates and nutritionally balanced.
133 - 220	20 -40	Could be harmful if consumed over long periods of time.
221 - 660	40 - 100	Cattle at risk, possible death losses.
661 - 800	100 - 200	Unsafe, high probability of death losses.
Over 800	> 200	Unsafe, do not use.

Source: CCREM (1987); US EPA (2004)

In the current study, the NO_3 content in the water in all sites were high and the water was not recommended for use. Therefore, NO_3 was identified as the basic toxic chemical in livestock drinking water in the study area as shown in **Table 7.9.** A report by MoWR (2001) indicated that the high NO_3 concentration in water wells was associated with poor waste handling and the presence of large livestock population around the water sources that left dung and urine in nearby wells (MoWR, 2001). Hand-dug wells in the rift valley zone were also found to have high NO_3, which was probably caused by N fertilizers, animal manure, crop residues and industrial waste and human waste in nearby toilet pits (MoWR, 2002).

In Ethiopia, public sanitation services for public toilet facilities, sludge and related environmental health services are generally inadequate and did not meet the required demand. Water bodies around cities and towns were mostly polluted by septic tanks and pit latrine overflows as well as waste water from various institutions and domestic sources (MoWR, 2001; 2002; UNESCO, 2004; Tamiru *et al.,* 2005; Solomon, 2006).

People residing in the rural areas left their human waste on land or at the banks of water bodies, and the waste was carried off in runoffs into natural water courses. Consequently, both surface and ground water in these areas were polluted by faecal matter leading to the prevalence of a wide variety of water-borne diseases (MoWR, 2001). The major problems in the rural settings were lack of dry pit latrines, the washing of clothes and bathing in rivers and the wide spread littering of animal dung which in one way or another contributed to the contamination of the water sources (UNESCO, 2004),

It can only be assumed that partly human and in other cases natural causes might have contributed to the pollution of water sources with NO_3. With respect to the state of industrial effluents in and around Addis Ababa, the Environmental Protection Authority (1999/2000) undertook analysis of waste water on riversides and reported that the pollution level was beyond the standard limits and it was unsafe for human and livestock to drink or irrigate vegetables (Tamiru *et al.,* 2005).

7.4.8.6 Chloride

Chloride ions have a number of functions in the body, including the regulation of osmotic pressure and pH balance along with Na and K (Olkowski, 2009). It also has an important role in digestion (Christensen *et al.,* 1996). High concentration of chloride ions is synonymous with salt (NaCl) toxicity. In ruminants, high concentration of Cl^- ions increase osmotic pressure in the rumen, which in turn may cause a decrease in microbial population, metabolic activity and a reduction in food intake (David, 2009). High concentration NaCl can result in dehydration, kidney failure, nervous system dysfunction and death in all animals (NRC, 1981). The Cl^- ion concentration in the study area was extremely high beyond the desired lower limit of 100 ppm and the maximum upper limit of 300 pm (CCREM, 1987). Lake Hora and Green Lake had extremely high Cl^- concentration, while Zekuala steel rolling factory effluent was at hazardous level for livestock use. Respondents reported that in 2008 about 30 oxen died after drinking water discharged from the Steel rolling factory. Rivers and water sources from dams had less Cl^- than stagnant water bodies such as lakes, ground water and factory discharges **(Table 7.11).**

7.4.8.7 Water hardness

Water hardness is generally a measure of Ca^- and Mg^- ions in the water (Olkowski, 2009). Zn, Fe, Sr, Al and Mn can also contribute to water hardness, although they are generally present in very low concentrations. Apparently, the degree of water hardness does not affect livestock production (NRC, 1981). Water is classified as soft at 0 to 60 ppm, moderately hard at 61 to 120 ppm, hard at 121 to 180 ppm and very hard at >180 ppm as shown on **Table 7.11.** However, water intake and milk production in cattle were unaffected by water containing up to 290 ppm of hardness (NRC, 1981). In the current study, the Ca and Mg contents in the water bodies were very low, and the degree of water hardness was categorized as soft.

Table 7.11: Calcium and magnesium concentration and water hardness level

Water hardness	Calcium and Magnesium (ppm)
Soft	0 - 60
Moderate	61 - 120
Hard	121 - 180
Very Hard	>181

Source: CCRME (1987); EPA (2004).

7.4.8.8 Sodium

Na_2SO_4 also known as Glauber's salt is a well-known laxative (Olkowski, 2009). Mg and Na on their own pose little risk to livestock, but their association with SO_4 is a major concern (Olkowski, 2009). Water with > 800 mg/L Na can cause diarrhoea and a decrease in milk production in dairy cows (NRC, 1981). High level of Na, a major component in salt may require adjustments of rations. Care should be taken when removing or reducing salt from pig and dairy rations to ensure that it does not result in Cl deficiency. Salt may be reduced in pig diets if the Na in the water exceeds 400 mg/L (Patience *et al.,* 1989). The water sources in the study area had Na concentration less than 200 mg/L as shown in **Table 7.12.**

7.4.8.9 Magnesium

$MgSO_4$ also known as Epsom salt is undesirable in water because of its laxative effect (Olkowski, 2009). An upper limit of 300 to 400 mg/L has been suggested for dairy cows

(Christensen *et al.,* 1996). Mg level in water in the study area was considerably lower than the standard limit as shown on **Table 7.12**.

7.4.8.10 Total phosphorus

Total P is a measure of both inorganic and organic forms of P (Olkowski, 2009). P may occur as dissolved or particulate matter. It is an essential plant nutrient and is often the most limiting nutrient to plant growth in fresh water. It is rarely found in significant concentrations in surface water. It is generally reported in µg/L or mg/L. The total P concentration in lakes in the study area was also affected by anthropogenic inputs. The level of P ranged between 58.28 and 197.27 mg/L (**Table 7.12**)

Table 7.12: Chemical composition of minerals in water samples

	Sample site	P (mg/L)	N (mg/L)	K (mg/L)	Ca (mg/L)	Mg (mg/L)	Cl (ppm)
1	Godino dam	26.90	7.39	2.4	20	7.16	64.98
2	Mojo River I	35.87	19.2	2.33	13.1	5.84	134.96
3	Belbela pond I	80.70	4.15	2.69	13.9	4.68	49.98
4	Belbela River II	103.12	4.0	2.23	15	5.18	34.99
5	Wedecha dam	242.11	12.9	7.23	22.67	9.75	84.97
6	Keta pond	58.28	2.32	5.22	12.8	8.43	134.96
7	Zekuala steel factory pond	192.79	60.58	6.28	8.06	2.52	1054.67
8	Oxford factory chemical discharge	112.09	13.93	5.13	21.55	7.92	184.94
9	East African chemical flow	990.84	73.6	4.4	10.69	4.36	224.93
10	Hora Lake	58.28	170.54	13.78	8.13	35.13	2889.10
11	Mojo River II	53.80	23.51	3.56	18.09	9.77	279.91
12	Tap water	44.83	5.32	2.77	15	17.04	234.93
13	Green Lake	197.27	97.84	63.21	7.13	5.01	6000.00
14	Cheleleka swamp	0.00	33.33	1.46	9.43	2.81	144.96

However, since P is generally the most limiting nutrient in the soil, its input in fresh water systems can cause extreme proliferation of algae growth. Inputs of P are the prime contributing factors to eutrophication in most fresh water systems. A general guideline regarding P and lake productivity shows that: <10 µg/L of P is considered oligotrophic; 10 to 25 µg/L of P is mesotrophic; and >25 µg/L of P is considered eutrophic (NRC, 1981). In the current study, all water bodies were categorized as eutrophic as shown in **Table 7.12.** Anthropogenic sources of P were sewage treatment plants, industrial effluent and farm waste.

7.4.9 Microbial properties

There are many micro-organisms in water sources and most of them are quite harmless. There are, however, certain organisms where caution must be taken. The green scum that builds up in livestock drinking troughs and tanks is algae. It cannot grow without sunlight. Some blue-green algae are toxic (EPA, 2004). Coli form counts below 50 micro-organisms per ml of water are safe for cattle (Pond *et al.,* 2005). Other possible contaminants include: coccidia, staphylococcus, streptococcus, viruses, etc. Micro-organisms can enter a well that does not have proper surface protection. A well is said to be situated improperly if the drainage from livestock dung droppings, urine or cracked well casing allows bacteria to enter the water supply (MoWR, 2002).

Signs of blue-green algae poisoning are diarrhoea, lack of coordination, labored breathing and death. A suggested treatment for algae poisoning is large quantities of medical-grade charcoal and mineral oil. Green Lake in the study area that was occasionally used for watering livestock was full of blue-green algae. Further research should be considered on the impact of water from the Green Lake on animal health and for environmentally sustainable and economic use of the blue-green algae in the lake.

7.5 Conclusions and recommendations

Overall, there was an indication of a decline in water resources on per capita basis. The major contributing factors were combined pressure of human and animal population on natural resources that led to excessive deforestation, loss of biological diversity, overgrazing, soil degradation and various forms of pollution and contamination. The global climate change also played a role in the decline in water resources due to the decrease in annual precipitation and increasing temperature. Urbanization and economic growth increased the demand for milk and meat, which required additional water use for each unit of increased animal protein. The demand for milk and meat is expected to double in the next 20 years with an annual projected growth rate of between 2.5 to 4%. Increasing milk and meat production will require more water per unit of the product. This issue has raised concerns on how to meet the water requirement of livestock based on future protein demand, population growth, economic prosperity and climate change.

Livestock water intake was influenced by the type of species, breed and physiological state. Under high temperature, water consumption increased by 2.1% for each $^{\circ}$C change in temperature. Therefore, with increasing temperature livestock water requirement increased at an increasing rate, which was a danger signal to smallholder farmers who live under subsistence farming. However, it was understood that livestock drinking water does not have significant share in total water resource depletion compared to water that is used for the production of animal feed and sanitary services.

The results showed that livestock helps to sustain water resources in ecosystems by using the little available water in the crop residues and metabolic water recharge from the oxidation of feeds. The water recharged through the feeding of crop residues could have been lost through evapo-transpiration, volatilization and trampling. However, if livestock production were to be based solely on the use of crop residues it would have a negative consequence on nutrient recycling. Growing of fodder legumes and the use of fodder as supplements to crop residues would be the most practical and cost-effective method of improving nutritional value of crop residues. Increasing land slope and grazing intensity reduced water infiltration rate into soil and enhanced soil erosion through runoff. Therefore, care must be taken when selecting ploughing methods based on land slopes and the use of different feeding methods to reduce overgrazing.

It was also concluded that livestock also contributed to water recharge when manure was used in the fields by increasing soil water retention capacity. Manure increased soil moisture content by 10% both under medium and heavy grazing conditions. Therefore, livestock had a positive water balance role in ecosystems when manure was used for fertilization. Thus, alternative water recharging mechanisms such as water recycling, effective soil and water conservation, reforestation and appropriate water use have to be sought. Family planning has to be considered to slow down human population growth. Overall, the water recharging schemes have to integrate the planning and implementation of water resource with community participation. Physico-chemical properties of water such as pH, total dissolved solids, toxic compounds and bacteria were higher than standard limits and as a result water quality was unsafe for human and livestock consumption. Therefore, development programmes and environmental groups have to consider ways of maintaining the quality by protecting water bodies, and at the same time improving the quality of water in water sources that are contaminated by excessive nutrient load.

CHAPTER 8:

LIVESTOCK, CLIMATE CHANGE AND TECNOLOGICAL OPTIONS

8.1 Introduction

Climate change has already influenced agricultural ecosystems in several regions of the world (IPCC, 2007) where there is ample scientific and historical evidence of the effects. History has shown that human beings are capable and have the capacity to adapt to changing climates. However, in the last recent decades unexpected natural disasters have become more frequent and their effects on natural ecosystems are remarkable (Easterling *et al.,* 2007). This has directly or indirectly affected existing agricultural production systems. In addition to these disasters, societies are expected to change their life styles to realize more income growth (World Bank, 2010). Thus, agricultural production systems will require effective adaptive strategies to overcome gaps between demand and supply of food and other societal needs (Easterling *et al.,* 2007).

Central Ethiopian highlands constitute one of the major food producing agro-ecologies in the country. Farmers have been struggling to maintain their livelihoods by continuously trying to produce food for subsistence. But the production systems have often become non-resilient to climatic shocks, variability and climate change. As a result, famine and hunger have killed millions of people and occasional flooding has also displaced thousands of them from their homes (Meze-Hausken, 2004).

The poor living conditions of farmers in the highlands as a result of anthropogenic and natural disasters demand the development and implementation of methodologies to address issues of vulnerability to climate change (Deressa and Hassan, 2009). Research on climate change in the highlands often targeted crop production decisions that were sensitive to possible future climatic conditions (NMSA, 2001). Efforts have been made for assisting farmers and policy makers in the crop sub-sector to improve their planning and make better management decisions (Deressa and Hassan, 2009). Most of the past studies have been oriented to finding agronomic practices that could reduce potential negative impacts of climate change and variability on crop production e.g., sowing dates, cultivar characteristics, fertilizer use, etc. (FAO, 2000). However, little research has been conducted on the effect of climate change and climate variability on the livestock component of mixed farming systems in the highlands. Under mixed crop-livestock production systems, crops and livestock production are integrated in the same farms. Thus, the farming systems in the cropped areas include the use of animal draught power for traction, threshing and transport; and in turn crop residues are used as animal feed and manure for fertilization (Hadera, 2001). Animals are also utilized for meat, milk and hide production to generate income (Diao *et al.,* 2005).

The crop-livestock mixed production systems in the current study area were characterized by mild climatic conditions which were suited for growing a wide range of crops with occasional rotation with cereals and pulses (IPMS, 2004). Crop residues were major sources of animal feeds. These characteristics provided farmers with very high flexibility for modifying management practices for better adaption to climate variability and climate change. On the other hand, that same flexibility resulted in huge challenges since the tools to improve planning and decision-making must consider a very wide range of possible activities, inputs, market mixes and interactions.

This chapter reports about the assessment of the effect of climate change on livestock production at smallholder level in the Ethiopian highlands by taking Adaa district as a case study. It also presents forward adaptive management practices to improve the performance of agricultural systems and decision-making in relation to climate change.

8.2 Research methodology

8.2.1 The study area

The study area was Adaa district which is ecologically in the high potential livestock and crop production systems in Ethiopia (IPMS, 2004). Administratively, it is one of the 12 districts in East Shoa zone, Oromia Regional State in Ethiopia and is located about 45 km southeast of Addis Ababa. The area falls within longitude 38^o51’ 43.63’’ to 39^o04’ 58.59’’ E and latitude 8^o46’ 16.20’’ to 8^o59’ 16.38’’ N, on the western margin of the great East African Rift Valley.

The study area has a bimodal rainfall pattern, with the short rains occurring from March to May and the main rains from June to September. Based on the long-term data, more than

75% of the annual rainfall is received during the main rains, when cropping normally takes place (Kahsay, 2004). The highest rainfall was recorded in 1966, when the annual rainfall was 1287 mm, much higher than the average 890 mm. The short rains are sometimes erratic but there is no cropping taking place during this period, except that it is important for softening the soil to facilitate land preparation and also to promote the growth of pasture grasses for livestock.

Sixty-year data (Kahsay, 2004) indicated that the average minimum and maximum air temperature ranged from 8^oC to 28.2^oC, respectively. However, mean annual temperature is 18.5^oC. Highest average temperatures were observed for March, April, May and June, while October, November and December had the lowest average temperatures.

The agro-ecology in the district is best suited for diverse agricultural production. The district is nationally popular for it excellent quality Teff. Wheat is the next abundant crop that grows in the district. Pulses, especially chickpeas, grow in the bottomlands on residual moisture and in rotation with cereals.

The general altitude in the district ranges from 1500 to > 2000 m above sea level. Two major agro climatic zones were identified in the district (IPMS, 2004) as: (a) the mountain zone located > 2000 m, covering 150 km^2, (9%) of the area, and (b) the highland zone at an elevation of 1500 to 2000 m extending > 1600 km^2 which covers 91% of the area.

8.2.2 Meteorological data

Sixty-year meteorological data (1951-2009) for rainfall, temperature and relative humidity; three decades of sunshine hours and two decades of wind speed, were obtained from the Ethiopian National Meteorological Service Agency (NMSA). The weather data reported here is based on information from Debrezeit Air Force weather station which is the oldest station located within the study area. The meteorological data were compared by decades.

8.2.3 Socio-economic survey

As part of the study, 110 farmers who participated in extension programme provided by the Ministry of Agriculture were selected for the survey. The reason for the selection was that these farmers were most likely to be able to provide information on climate change indicators and adaptation in their location. The farmers were asked about their perception of climate change, indicators for climate change and the adaption methods they have followed to mitigate climate change. Structured questionnaires written in English were used as research tools to collect data. Questionnaires were made simple by use of open-ended questions. Interviews were conducted orally with household heads (either male or female) in their homes. After collecting data, the first step was to transfer the data onto a spreadsheet using the Statistical Package for Social Sciences, version 17.0.1 (SPSS, 2008).

8.2.4 Suitability analysis using DIVA-GIS

DIVA-GIS is a geographical information system that is used to analyze plant biodiversity data. It was developed at the International Potato Center (CIP) to help curate gene bank data. Additional support was subsequently obtained from IPGRI (DIVA-GIS website: http://www.diva-gis.org).

DIVA-GIS implemented EcoCrop to predict the adaptation of crops over geographical areas (White *et al.,* 2001) that could also be used to estimate crop residue potential for future livestock feed. Currently, only temperature and precipitation data are used to make this prediction. To determine the suitability of a certain crop in a growing season, the following temperature parameters were used:

KTMP: absolute temperature that will kill the plant
TMIN: minimum average temperature at which the plant grows
TOPMN: minimum average temperature at which the plant will grow optimally
TOPMX: maximum average temperature at which the plant will grow optimally
TMAX: maximum average temperature at which the plant will cease to grow

To determine the suitability of rainfall in an area for particular crops, the following rainfall parameters were used:
Rmin: minimum rainfall (mm) during the growing season
Ropmin: optimal minimum rainfall (mm) during the growing season
Ropmax: optimal maximum rainfall (mm) during the growing season

Rmax:	maximum rainfall (mm) during the growing season

EcoCrop module runs for both rainfall and temperature or separately. In the last case, the minimum value of the two parameters for each growing season is used to compute suitability. To run the module we selected a species in the select tab, searching for species using options in filter by option. Then we selected the crop of interest by clicking on it. In the parameters tab, we selected temperature and rainfall parameters from the EcoCrop database and changed them as desired. In this case the temperature and rainfall were predicted from three climate change models (CGM2, HaDCM3 and PCM) for 2050 and 2100 (Deressa and Hassan, 2009). Teff and wheat were the two selected crops to run the DIV-GIS. These two crops were selected for their dominance in area coverage as well as relevance as crop residues for livestock feeding in the highlands, and also due to the agronomic and nutritional similarity of Teff with other grass species (Tareke, 2010).

8.2.5 Data analysis

Detailed statistical analysis of the data was done using SPSS (2008) version 17.0.1. Weather data were analysed for decade means and tested for their significant differences among decades. Variables that were the most representative of the study area were extracted from the socio-economic survey and computed for univariate analysis (effects of climate change on livestock production, perceptions on climate change and factors that influenced decisions to adapt to climate change). Information on technology option for livestock adaption to climate change was reviewed from secondary data.

8.3 Results and discussion

8.3.1 Weather data for the past sixty years (1951-2009)

8.3.1.1 Rainfall variability and trend

Precipitation in liquid and frozen form is one of the most important weather variables for agricultural systems. Plants rely on water from precipitation to survive and to recharge the soil. Periods of no precipitation result in drought, and periods of excess precipitation cause floods (ASA, 2005). Both extremes have a major impact on agricultural crops, livestock and operations. However, many other natural and human factors can affect water availability (Wilhite and Glantz, 1985) whether for the growth of crops, pastures or for household use. The interconnectedness of changes in temperature, evapo-transpiration and other physical factors such as soil fertility and vegetation cover affect water availability (Meze-Hausken, 2004).

The baseline climate data was developed using historical data of temperature and precipitation from 1951- 2009 at Debrezeit Air Force Station. The data were obtained from National Meteorological Agency of Ethiopia archives. Mean annual rainfall showed large spatial and temporal variation. The Ethiopian National Meteorological Services Agency (ENMS) defined 50 to 75% of a 30-year average as 'below normal' rainfall and designated it as dry and 0 to 50% average rainfall as 'much-below-normal' rainfall (Meze-Hausken, 2004); whereas an annual rainfall above the 30-year average was considered a wet year. The study area experienced both dry and wet years over the last 60 years. NMSA (2007) reported that 1965, 1984 and 2001 were extremely dry years, while 1961, 1964, 1967, 1977, 1996 and 2007 were very wet years. Studies by NMSA showed that there is a link between *El-Nino* and *La-Nina* phenomena and the occurrence of rain in Ethiopia (NMSA, 2001).

In the current study decade-based trend analysis of annual rainfall showed that rainfall remained more or less constant when averaged over all decades. The LSD analysis showed that from decade three there were no significant differences in rainfall amount between the decades. However, there were significant differences between decades 1 and 2 and the others decades (3, 4, 5 and 6). Generally speaking the rainfall has increased by 7.5% in the past three decades with an increase of rainfall amount by 2% for each decade **(Figure 8.1).** This is in agreement with MMSA (2001) findings which reported an increasing trend in annual rainfall in the central Ethiopian highlands.

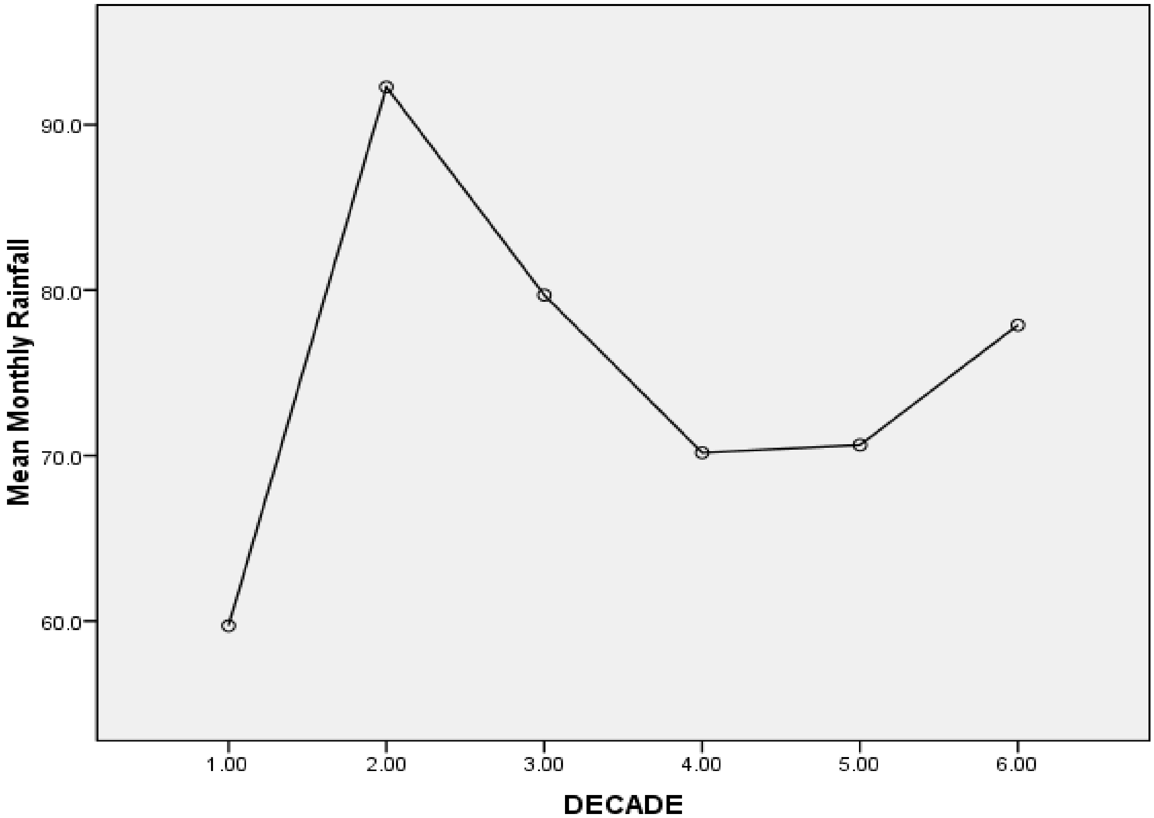

Figure 8.1: Estimated monthly mean rainfall (mm) by decade
(Decade 1 = 1951-59, Decade 2 = 1960-69, Decade 3 = 1970-79,
Decade 4 = 1980-89, Decade 5 = 1990-99, Decade 6 = 2000-09).

8.3.1.2 Temperature variability and trend

The survival of crops, insects and animals is determined largely by the temperature micro-climate (ASA, 2005). In agricultural systems, temperature is used as an indication of when crops should be planted and how rapidly a plant or insect develops. The growing degree unit (GDU) has been developed as one method of measuring the rate of plant development (ASA, 2005). This unit is defined as: GDU = $(T_h + T_l) / 2-T_b$.

Where; T_h = the daily maximum temperature,

T_l = the daily minimum temperature, and

T_b = a base temperature below which a plant or insect is assumed not to grow.

The cumulative GDU is also referred to as thermal time. Crops may be classified according to how many GDUs are required to reach maturity. Therefore, records on extreme temperature (absolute TMax and absolute TMin) are also important for agricultural production. Ethiopia has experienced very warm years in 1957, 1958, 1973, 1987, 1995, and 2002, and very cool years in 1964, 1967, 1968, 1975, 1977, 1989 and 2003 (NMSA, 2007). The average annual maximum temperature has increased by about 0.08^{o}C for every decade **(Figure 8.2),** which is close to the estimate by NMSA (2001) of 0.10^{o}C overall.

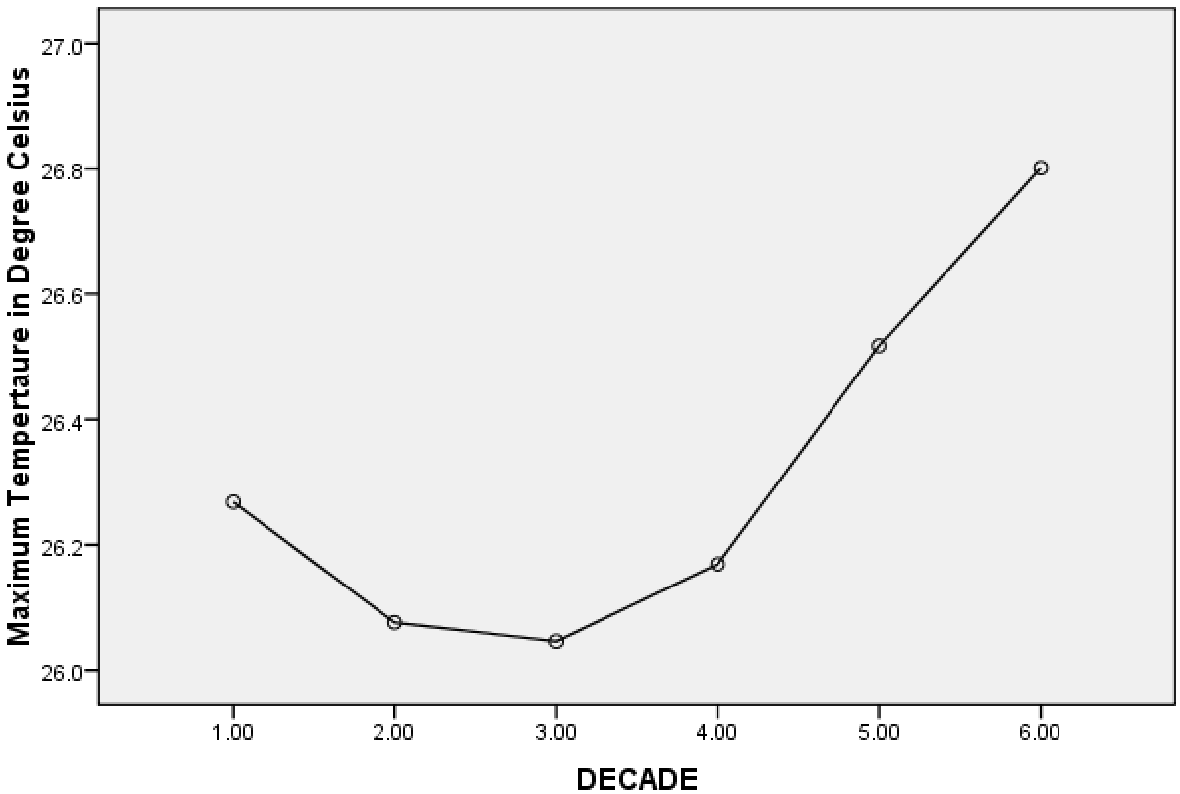

Figure 8.2: Estimated monthly mean maximum temperature by decade

(Decade 1= 1951-59, Decade 2=1960-69, Decade 3=1970-79, Decade 4 = 1980-89, Decade 5=1990-99, Decade 6= 2000-09)

Similarly, the average annual minimum temperature in the study area has increased by about 0.08^{o}C on average, totaling 0.5^{o}C in the past six decades **(Figure 8.3).** It is interesting to note that the average annual minimum temperature and the average annual maximum temperature increased at the same rate. However, in both minimum and maximum temperatures the LSD analysis shows that there were no significant differences in temperature across most of the decades except decade six, in the case of maximum temperature, which indicated that maximum temperature increased significantly in the sixth decade (2000-2009). For minimum temperature the significant level started in the 4th decade (1980s). It was highest in the fifth decade (1990s) and then declined in the sixth decade.

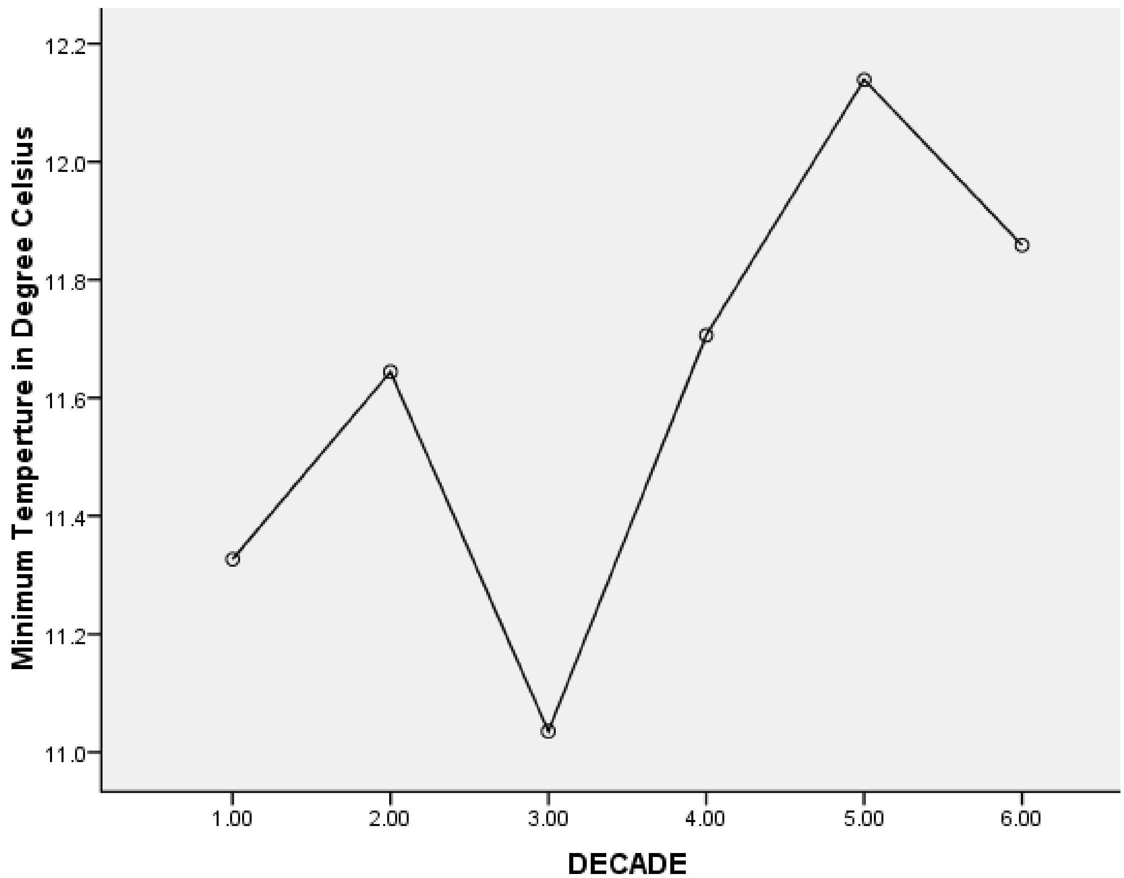

Figure 8.3: Estimated monthly means minimum temperature by decade
(Decade 1 = 1951-59, Decade 2 = 1960-69, Decade 3 = 1970-79, Decade 4 = 1980-89, Decade 5 = 1990-99, Decade 6 = 2000-09)

8.3.1.3 Relative humidity

Relative humidity, temperature and pressure are fundamental variables that characterize the local state of the atmosphere (ASA, 2005). Within the realm of agriculture, relative humidity measurements have a wide range of applications, including the prediction of plant disease and livestock feed requirements (ASA, 2005). In the present study, there were no significant differences in relative humidity across the decades from 1951-2009, as shown in **Figure 8.4.**

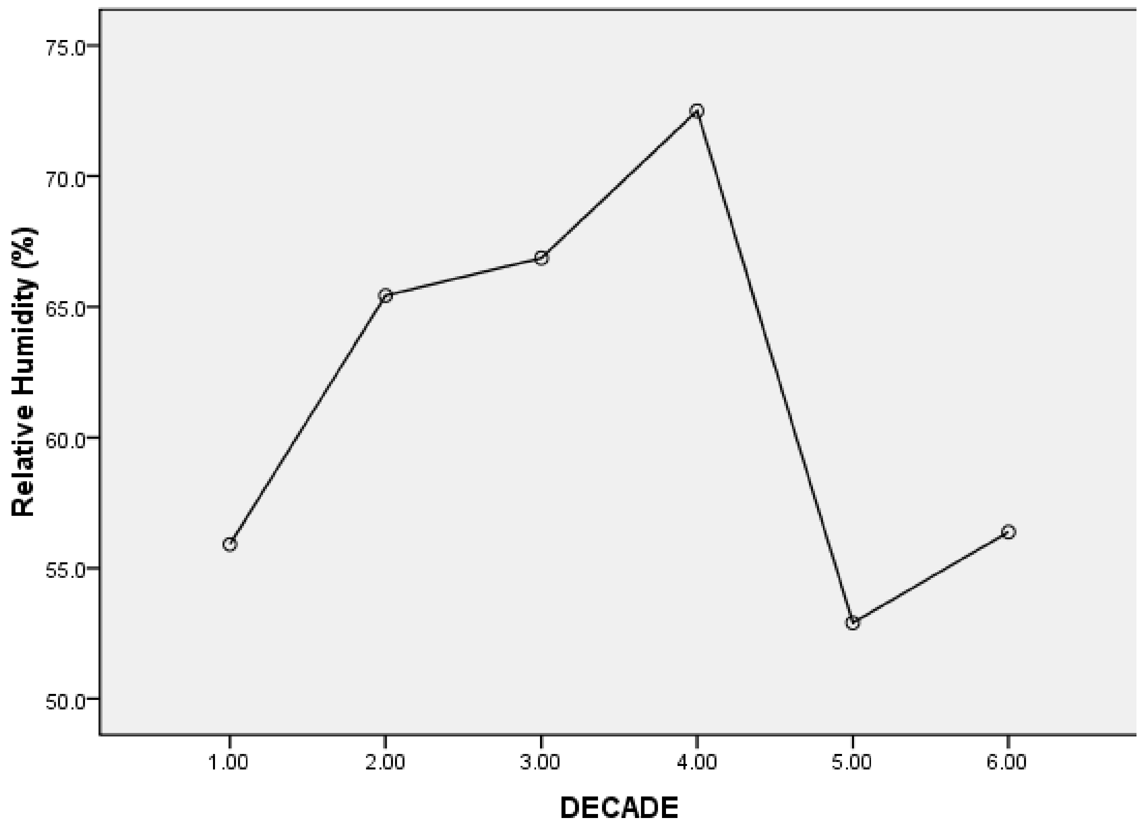

Figure 8.4: Estimated monthly mean relative humidity by decade

(Decade 1 = 1951-59, Decade 2 = 1960-69, Decade 3 = 1970-79, Decade 4 = 1980-89, Decade 5 = 1990-99, Decade 6 = 2000-09)

8.3.1.4 Sunshine hours

Solar radiation is the largest energy source and is able to change large quantities of liquid water into vapor (ASA, 2005). The potential amount of radiation that can reach the evaporating surface is determined by its location and the time of the year. Due to differences in the position of the sun, the potential radiation differs at various latitudes and in different seasons. The actual solar radiation reaching the evaporating surface depends on the turbidity of the atmosphere and the presence of clouds which reflect and absorb most of the radiation. When assessing the effect of solar radiation on evapo-transpiration, it shows that not all available energy is used to vaporize water. Part of the solar energy is used to heat up the atmosphere and the soil profile (ASA, 2005). In the current study, there were significant differences in sunshine hours in the last three decades. It increased from an average of 8.15 hours per day to 8.3 hours per day which contributed to an increase in evapo-transpiration as shown in **Figure 8.5.**

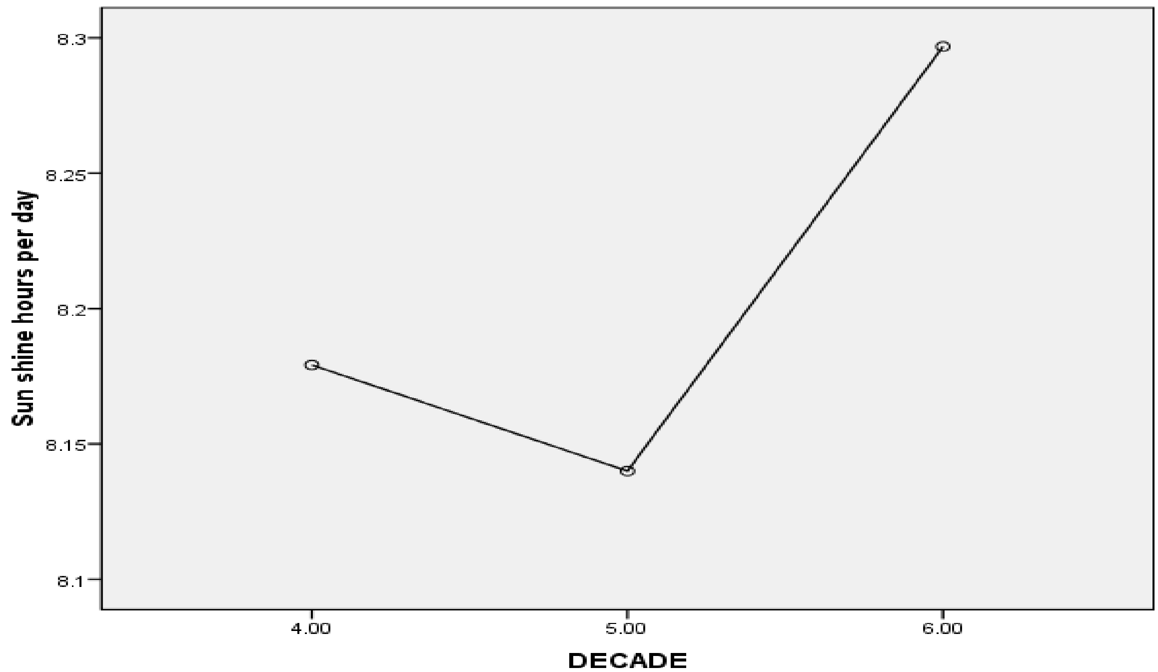

Figure 8.5: Estimated monthly mean sunshine hours by decade

(Decade 4 = 1980-89, Decade 5 = 1990-99, Decade 6 = 2000-09)

8.3.1.5 Wind speed

Agriculturists are interested in wind speed and direction, as these data are used to determine the location of different farm buildings relative to each other, and the design of wind breaks that protect the homestead and livestock during the winter (ASA, 2005). Real time wind speed and direction information is critical for the spraying of crops and for pest control. Wind currents transport pollen that ensures the fertilization of self-pollinated crops. Wind provides ventilation in livestock buildings, cool animals in summer and disperse odor. Light wind speed tends to move odor along the surface with little mixing, resulting in the concentration of the odor and discomfort. Strong wind tends to be more turbulent and the odor is mixed and carried up and away from the surface. In this case there is not much of a problem. However, strong wind can damage crops and farm structures. Wind also transports insects and disease germs that affect crops. Wind also speeds up the rate of evapo-transpiration. The wind speed in the study area showed significant differences between decades and showed a decline in the last two decades, which was estimated at 1.6% as shown on **Figure 8.6.**

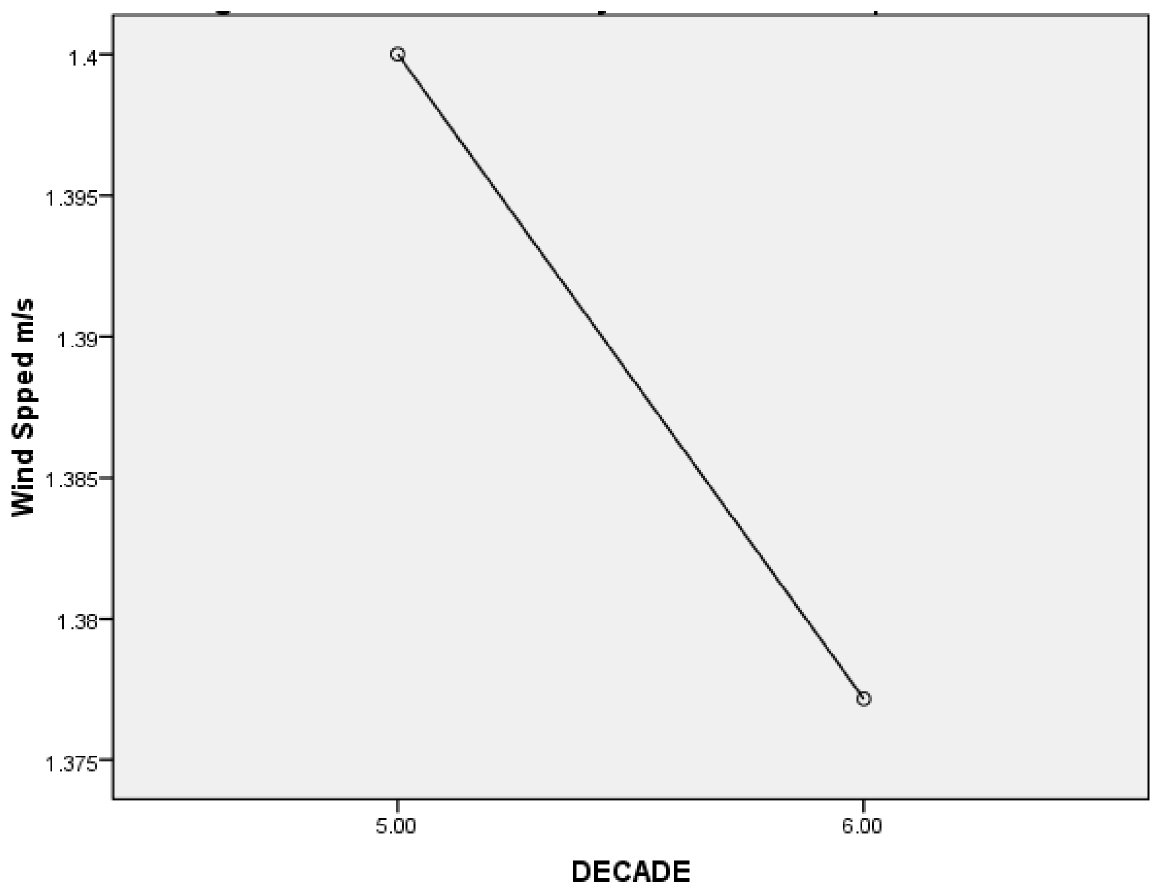

Figure 8.6: Estimated monthly mean wind speed by decade

(Decade 5 = 1990-99, Decade 6 = 2000-09)

8.3.2 Future climate change scenarios

In this study temperature and rainfall were changed based on future climate change predictions for Ethiopia in 2050 and 2100 (Deressa and Hassan, 2009). Predicted values of temperature and rainfall were taken from three climate change models (CGM2, HaDCM3 and PCM). The predicted values for the scenario analysis were taken from Colorado University (Strzepek and McCluskey, 2006; cited in Deressa and Hassan, 2009). **Table 8.1** shows the predicted values of temperature and rainfall from the three models for 2050 and 2100. As can be observed from this table, all the models forecasted increasing temperature levels for 2050 and 2100. With respect to rainfall, while the CGM2 predicted decreasing rainfall for 2050 and 2100, both HaDCM3 and PCM predicted increasing rainfall over these years.

Table 8.1: Climate predictions by SRES models for 2050 and 2100

Model	**Temperature (^oC)**			**Precipitation (mm)**		
	Current	2050	2100	Current	2050	2100
CGM2	21.25	24.51	29.26	767.7	647.5	502.7
HADCM3	21.25	25.07	30.66	767.7	835.3	934.6
PCM	21.25	23.50	26.69	767.7	808.3	856.7

Source: Deressa and Hassan (2009)

8.3.3 Current crop production conditions

Vulnerability assessment in the agricultural sector was accomplished for wheat and Teff, since these two crops were among the five major crops growing in Ethiopia. Teff is a C_4 plant (Ketema, 1997), and it is intermediate between a tropical and temperate grass. Teff is adapted to environments ranging from drought stress to waterlogged soil conditions and diverse soil types (Ketema, 1997). Teff production has been reported at altitudes as low as the sea level and up to 3 000 m above sea level. Under the current conditions, Teff is suitable in most areas of the country covering different agro-ecological areas **(Figure 8.7).** In

Ethiopia Teff occupies >2.8 million hectares annually, which is 25 to 30% of the total area covered by cereals (CSA, 2010). It is a staple food for about 50 million Ethiopians who make 60% of the population. The quality of crop residues from Teff is equivalent to grass species like Rhodes grass (Alemayehu, 1997), hence the crop residues from Teff are important animal feeds.

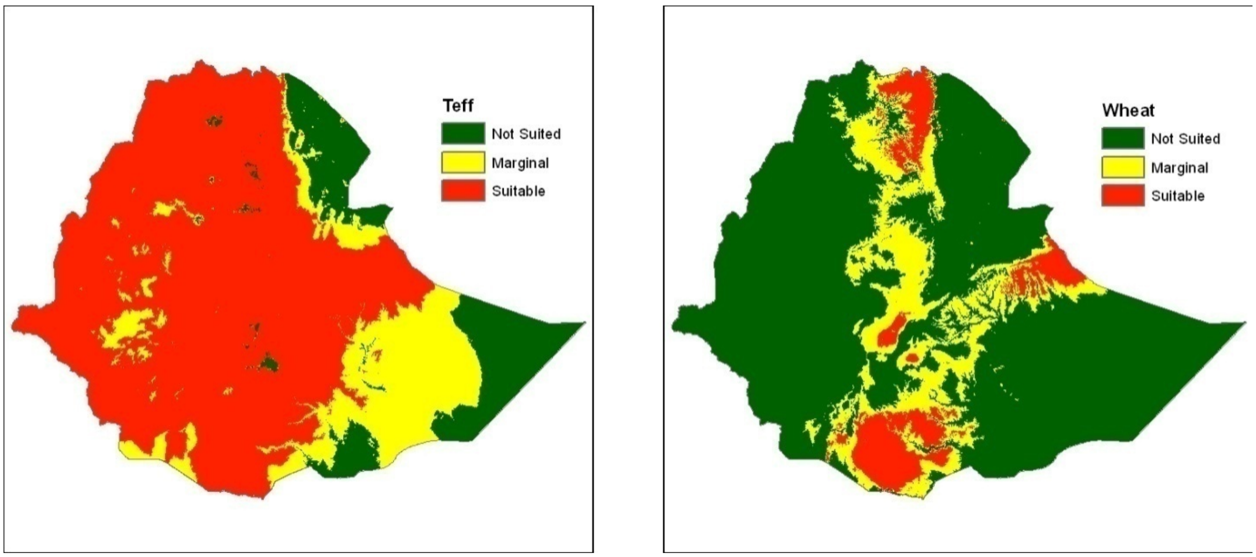

Figure 8.7: Current suitable areas for Teff and wheat production
Source: DIVA-GIS website (http://www.diva-gis.org).

Figure 8.7 shows the current potential Teff and wheat growing areas in Ethiopia. Wheat is one of the five top crops grown in the country. Ethiopia is the second largest grower of wheat in sub-Saharan Africa. About 900 000 ha of bread and durum wheat are cultivated annually, primarily as highland rain-fed crop. Rainfall and minimum temperature are the key determinants of potential wheat areas. Minimum rainfall of at least 350 mm and a minimum temperature between 6 to 11°C are required during the wettest quarter of three months of growing period (White *et al.,* 2001).

8.3.4 Future geographic coverage of Teff and wheat

8.3.4.1 Potential wheat production areas

Water deficit and warm night temperatures are the key factors limiting bread wheat production in Ethiopia (White *et al.,* 2001). Potential new areas for bread wheat production were identified by assuming that technologies could be developed to allow wheat to be grown in drier or warmer environments to increase the yield (White *et al.,* 2001). In the three climate change models (CGM2, HaDCM3 and PCM) it was estimated that areas suitable for wheat would expand to the east, north and west by 2050 and 2100 (**Figure 8.8**). In the three models, the unsuitable areas for wheat are mainly located on the marginal lowlands on the eastern parts of the country.

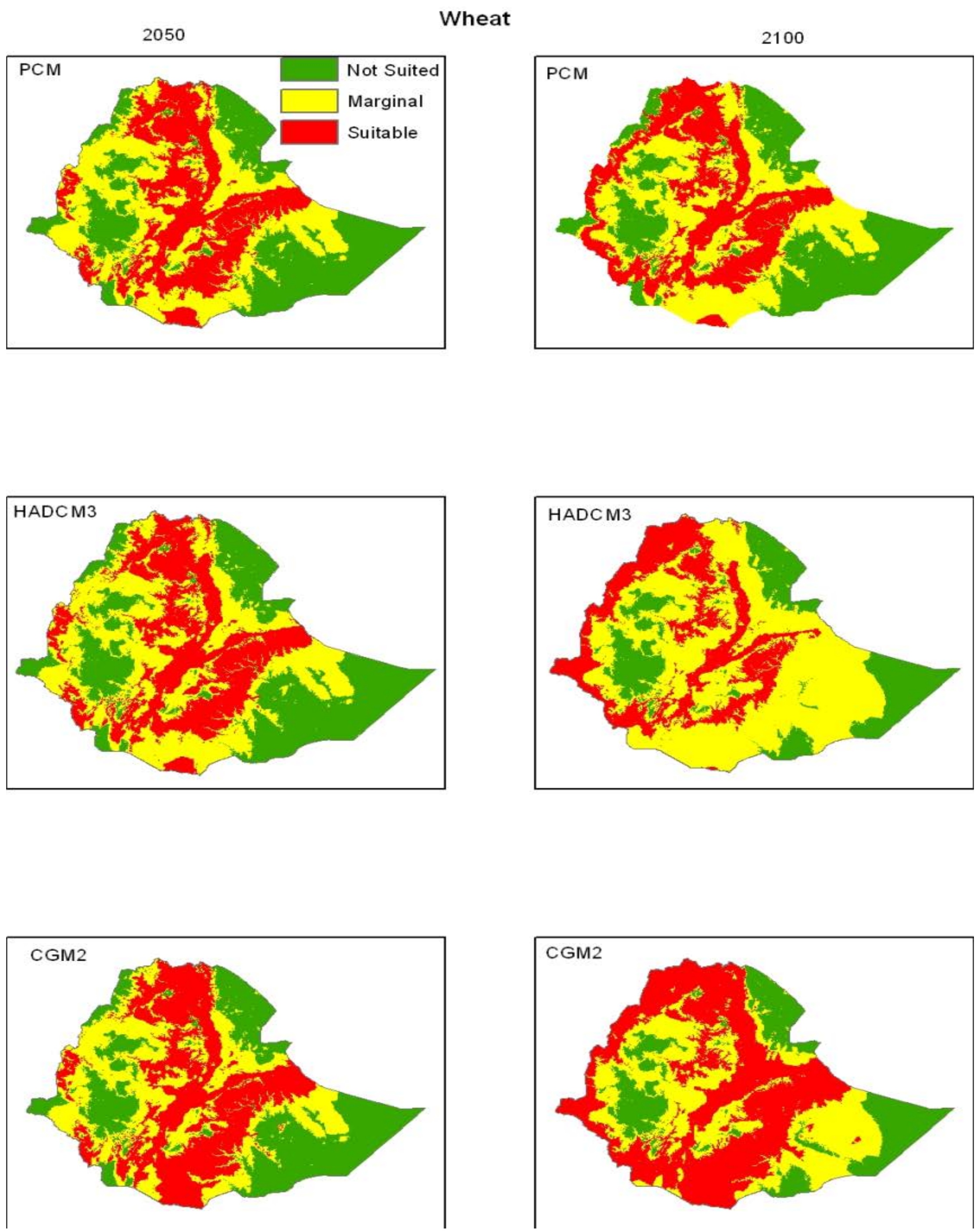

Figure 8.8: Forecast of areas suitable for wheat production in 2050-2100
Source: DIVA-GIS website (http://www.diva-gis.org).

8.3.4.2 Potential Teff production areas

Teff and other C_4 species like maize, sorghum and millet have an evolutionary advantage of a photosynthetic pathway over C_3 species such as wheat and cool season grasses (Stallknecht, 1997; Wondimu and Tekabe, 2001). The C_4 pathway allows more efficient use of water use and faster photosynthesis under high heat and light conditions than C_3 species (Stallknecht, 1997). Through DIV-GIS analysis the distribution of Teff in relation to climate change indicated that the generally suitable areas for Teff will shrink slightly in 2050 than 2100 under all models **(Figure 8.9).** Areas that are marginally suitable will expand more than those that are currently not suited, which indicates the possibility of producing Teff under climate change scenarios for higher temperature. The most affected zones are the eastern lowlands in Afar and Somali Regional States of Ethiopia. The highlands will remain suitable for Teff under all climate change models. Teff, maize and sorghum will produce best during periods of maximum heat unit accumulation.

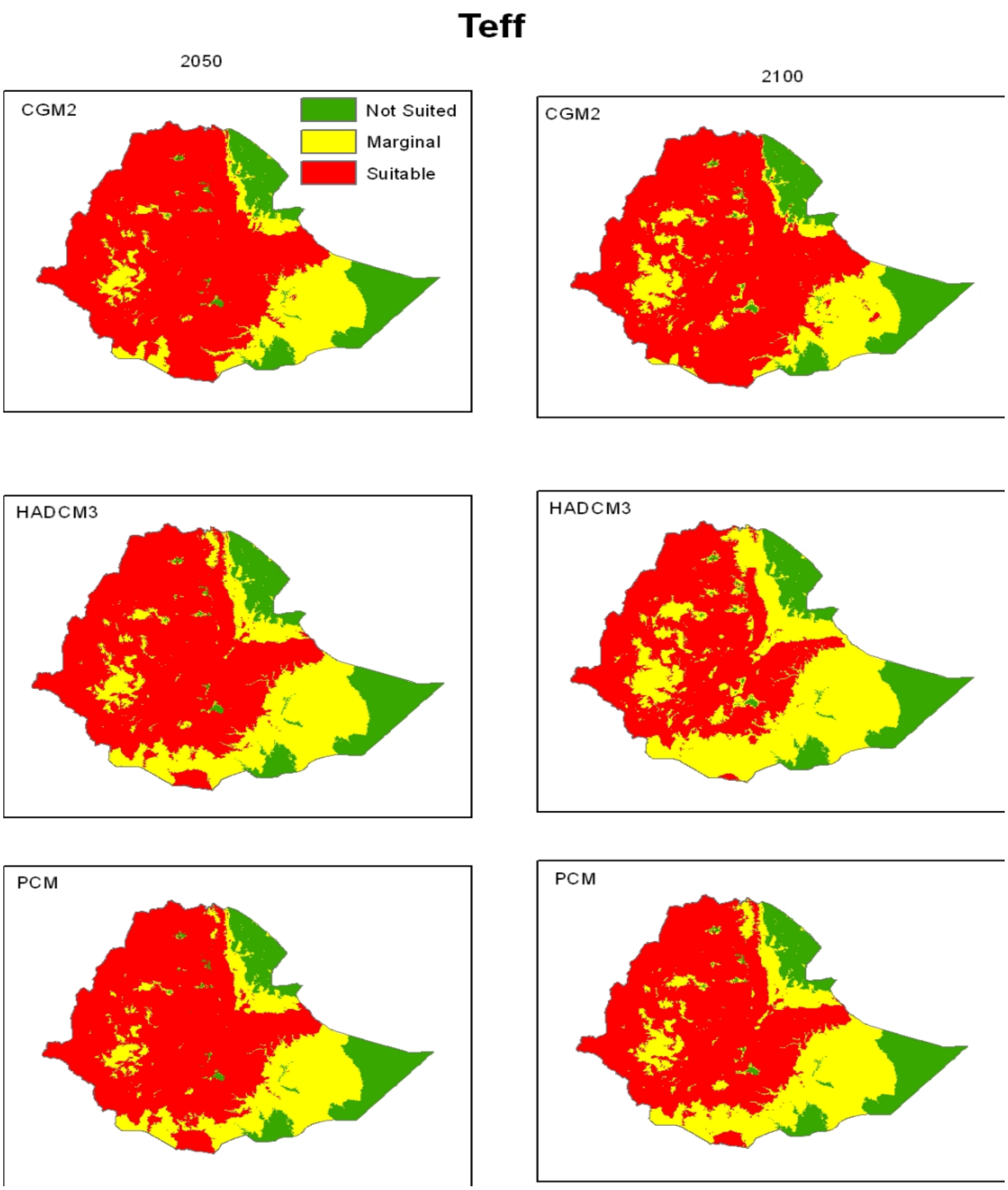

Figure 8.9: Forecast of areas suitable for Teff production in 2050 - 2100

Source: DIVA-GIS website (http://www.diva-gis.org).

8.3.5 Effects of climate change on livestock

Livestock production in the study area was dominated by crop production land use pattern, where crop residues contributed about 85% of the feed requirement (Alemu, 2002). From the climate change suitability analysis it was found that the Teff and wheat producing areas will expand with the change in temperature and precipitation for the coming 100 years or so.

In the lowlands, climate change is likely to impact on the amount and quality of forage produced in rangelands, which will reduce the reliability of production and the natural resource base on which livestock depends for browse and water (NMSA, 2001). Although there will be some direct effects on livestock, the majority of influences will be through changes in plant growth and the timing, quantity and quality of forage and crop residues available.

8.3.5.1 Global warming

Global warming is the result of increased GHGs destroying the ozone layer and warming of the earth (IPCC, 2007). It was predicted that the global temperature would rise by 0.2ºC every decade (IPCC, 2007), and by 2100, the temperature would have increased by 6.4^{o}C. This would be an equivalent of a two degree shift in latitude towards the tropics.

However, from the current study the 60-year data showed that temperature has risen by 0.08ºC per decade, indicating that geographic patterns have shown differences in global warming. Although there are differences in geographic positions, the effects of GHGs are borderless, meaning that even if no GHG entered the atmosphere from certain locations, global warming would continue to affect locations that emit less GHG (IPCC, 2007).

The level of CO_2 rose sharply in the last decade (FAO, 1996). It is estimated that by 2100, CO_2 level will be triple the pre-industrial times (IPCC, 2007). The rising CO_2 level has a major effect on plant growth. Positively, greater resource efficiency will increase plant growth (FAO, 1996). FAO (2002) also reported that the loss of moisture will cause greater fixation of CO_2 per molecule of water lost, which will improve water efficiency. Therefore, increased CO_2 has a positive effect on plant biomass yield, water use efficiency and effective use of some nutrients.

Unlike the effects of increased CO_2 on the atmosphere, the effects of rising temperature will mostly be negative and offset the positive effects of CO_2 on plant growth although the direct impact will vary in space and time (IPCC, 2007). It may be of benefit to some areas in high altitudes, since it will be possible to grow new crops where it was impossible to do so before due to environmental limitations. This evidence supports the idea that climate change and variability impact assessment and adaptation has to be done at local level due to variability in global ecology and resilience capacity (FAO, 1996).

Vegetation will become more lignified with low digestibility, inferior energy and protein content due to increased temperature; and as a result forage quality will be substantially poorer (NMSA, 2001). The establishment of crops will likely be difficult with little moisture content and will probably need to be planted earlier or require greater inputs, which will increase production costs. There will be greater induced heat stress for livestock. Water demand will become critical based on the location of livestock systems as has been seen recently with the spread of the tick-borne diseases and the expansion of pests and animal diseases (FAO, 1996; Sutherst *et al.,* 1996).

8.3.6 Farmers' perception about climate change

Farmers in the study area were asked about the accessibility to communal resources for all community members. They listed and ranked the resources as shown in **Table 8.2.** The highly accessed resources were water, wood and grasses. These resources are mainly used to sustain life of the rural community and their livestock. The resources were said to be highly depleted due to lack of management and communal ownership. Some of the resources like grass for roofing of houses, wild fruits and medicinal plants were depleted and their accessibility was limited because they were not available all the time. As human and livestock population increase, more pressure is put on all resources.

Table 8.2: Communal resources accessed by communities

	Communal resource type	Rank
1	Water for household use	1
2	Wood for household energy use	2
3	Wood for construction	3
4	Water for livestock use	4
5	Communal grazing	5
6	Charcoal making for income generation	6
7	Medicinal plants	7
8	Ritual trees and plants	8
9	Wild fruits	9
10	Grass for roofing	10

Respondents listed detritus and decomposers such as earthworms, millipedes, army worms, fiddler crabs, termites, ants, wood beetles, snails and birds, which existed during the time of their forefathers and the important role they had in decomposing and forming humus. Respondents described the status of detritus and decomposers as decreasing (39%); under threat (20%), endangered (50%) or have disappeared (5%). Some respondents (15%) believed that the presence of detritus and decomposers was a sign of good harvest; while others (10%) said it was an indication of good agro-ecological balance and (50%) said it was an indication of good soil.

Weather indicators for climate change were described as the change in patterns of rainfall, temperature and sunshine intensity. Some respondents (40%) mentioned erratic, un-seasonal and torrential rains that cause floods. Others (35%) mentioned the high temperature which caused difficulty in breathing, increased water consumption and faster growth rate for crops more than ever. People have changed their life styles such as light clothing and no fire is required to warm up people and animals. Light intensity has also increased as reported by 25% of the respondents who said that it has caused darkening of people's faces and early wilting of plants. All respondents agreed that indigenous trees and wild animals were endangered or have disappeared due to the increase in the area cultivated and greater livestock population.

8.3.7 Farmers' adaptation measures to climate change

Some farmers (25%) considered climate change as God's punishment for their sins. These farmers believed that the climate will become normal upon God's forbearance and forgiveness of human sins. About 75% of them believed that anthropogenic factors contributed to climate change. In the current study it was found that lack of land for cultivation was the major obstacle to farmers' adaptation to climate change. They needed land to practice different land rehabilitation practices such as conservation tillage, fallowing, intercropping and fencing. Other major issues identified by farmers were lack of information, financial credit, labor, water, and good soils. In the past three decades farmers adopted crops like chickpea and vetch expanding the acreage by three folds as these crops can survive on residual moisture and grow in crop rotations with cereals.

Other potential adaptation measures listed by farmers to cope with adverse impacts of climate change on crop production and crop residue were:

- Improving and changing management practices and techniques such as planting date, seeding rate, fertilizer application rate, etc.;
- Change in crop regions;
- Proper use of climate information for land use planning and early warning systems, etc.;
- Promoting irrigation agriculture;
- Enhancing erosion control and reforestation;
- Adopting suitable crop varieties and developing new ones that have food and feed value.

8.3.8 Livestock related technology options for adaptation

In the short term, improved management by intensifying "best practice" will mitigate the effects of climate change. This can be done by improving the quality of fodder production and feeding patterns, balanced stocking rate to match feed production, specialized and intensive animal rearing, mechanization of crop production to reduce dependence on livestock traction power, release crop varieties that have high food and feed value, better forage management based on agro-ecological suitability of specific forage and seasonal forecasting (Alemayehu, 2005). Improved herd management to include disease and pest management and monitoring as well as husbandry and welfare. The practices mentioned above provide immediate benefits regardless of climate change.

In the long term, adoption will be the key to success in coping with climate change. Vulnerability to climate change can be reduced by preparing, evaluating and implementing adaption strategies that reduce the risks of negative impacts whilst promoting advantages of new opportunities. Looking at new alternatives available and improving what already exists such as infrastructure, climate-ready breeds, and varieties of feed which will be better adapted to survive in that climate (IPCC, 2007). Civil society, non-governmental organizations, private sector and governments need to work with communities to implement proposed systems and provide support to farmers.

In cases where the effects of climate change may be inevitable or proposed options unviable, other options should be considered such as changing land uses. Extra support is required for these transitions to successfully occur. Sound policies will help to reduce disputes in dealing with GHGs, drought, water and pollution; to encourage development, evaluation and adoption of effective strategies to climate change (FAO, 1996). In addition, it is vital to ensure that communities have ongoing social, economic and environmental wellbeing for effective natural resource management.

The focus on options for livestock technology innovations is therefore, on livestock production, input supply and marketing in order to satisfy a growing demand without damaging the environment. Initiatives like pasture development, breed improvement, marketing, chemical treatment of crop residues, urea-molasses blocks, commercialization of green forage production will be considered as options for the reduction of the use of natural resources per unit of products. Adaptive measures for livestock-ecosystem balance should also include the integration of land degradation with forage development**.** The following technology options for livestock development for adaptation to climate change are elaborated.

8.3.8.1 Natural pasture rehabilitation

There are a number of valuable wild grasses, legumes and browse plants in Ethiopia because of the diverse climate. The highlands are rich in pasture species, especially legumes. Herbaceous legumes tend to increase with increasing altitude. There is a wide diversity of annual and perennial *Trifolium* species and annual *Medicago* in the highlands, particularly >2,000 m. At lower altitudes annual legumes are less abundant, but there are a number of browsing species.

According to Alemayehu (1997) despite the fact that research on indigenous species improvement has been minimal, most trials gave positive results. To improve the vegetation composition and the nutritional value of degraded pastures, research on oversowing with legumes and grasses has indicated that vetches (*Vicia dasycarpa* and *V*. *atropurpurea*) and local clovers (*Trifolium* sp.) were successful in the highlands. In mid-altitudes, the perennial *Desmodium uncinatum* has shown superior establishment with Rhodes grass (*Chloris gayana*) and Siratro (*Macroptilium atropurpureum*). Research and development testing over the last two decades identified promising forages that are suitable for pasture rehabilitation in a wide range of agro-ecological zones.

Weeds are a major problem in both perennial and annual pastures and forage crops; and unless they are controlled, productivity would be low. In Ethiopia weed control by herbicides, machine mowing, topping and hand weeding have been tried. Hand weeding was the best method. Since family and hired labour is plentiful and cheap, there is an opportunity to use it for weed control, and so there is a considerable opportunity to foster the development of improved pasture and forage crops on a large scale without major weed infestation problems.

8.3.8.2 Sown pastures and forages

Climate and land availability provide a good opportunity for forage production. In Ethiopia, most improved tropical species can be grown in the lowlands (1500-2000 m) and temperate species can be grown from elevations of > 2100 m up to 3000 m (Alemayehu, 1997). For introduced and improved forages, yield is higher than the naturally occurring swards and has higher nutritional value. In addition, the length of the productive season is longer for cultivated pastures than for natural pastures which provide an opportunity for dairy and beef cattle fattening and to develop and use pasture and forage on a large scale (Alemayehu, 1997).

Greater use of leguminous fodder trees and shrubs assists in increasing soil fertility, controlling soil erosion and providing firewood and timber. These legumes are well adapted to the current edaphic and grazing conditions, and they can be readily integrated into farming systems, because they retain their feed value in the dry season and show great success in higher potential areas of the country. Pasture establishment is relatively difficult in the highlands compared to the humid, warmer and lower areas, because of soils and climate. In the wet season, water logging, relatively low soil temperature and reduced long and short radiation limit the establishment and subsequent growth of pasture in the highlands. In these areas, perennial pastures are usually sown during the short rains (March and April) but annual forages are usually sown in June (Alemayehu, 2005).

Conventional methods of establishing pasture are tedious and labour demanding, especially in the highlands. Better ways are the low-cost methods such as backyard, undersowing and oversowing, which are more attractive to farmers. These strategies provide farmers with proper use of land for the cultivation of crop/pasture and forage/trees, and the products can be used for food, feed and firewood, respectively. Some perennial grasses can be planted vegetatively, e.g. *Festuca arundinacea*, *Phalaris arundinacea* and *Setaria sphacelata* which are well adapted to waterlogged conditions.

There is also considerable opportunity for the use of fodder tree legumes in agroforestry. Woody legumes provide a fodder hedge planted around the backyard, firewood, wood for construction of houses and farm equipment, wind breaks, for ceremonial purposes and for stabilizing bands and gullies. The current promotion of fodder tree legumes in the national agroforestry system is a good opportunity for the extension of a forage programme within farming systems. It contributes to environmental protection, natural resource management and food security (Alemayehu, 1997).

8.3.8.3 Intercropping

At the time of this study, arable farming was expanding at the expense of traditional or communal grazing lands. This has put pressure on grazing resources resulting in inadequate feed resources for livestock both in terms of quality and quantity (Diriba *et al.,* 2001). Under these conditions, development of integrated forage-cereal-livestock systems could accommodate and improve both crop and livestock production systems.

Integration of forage legumes into the cereal based cropping systems is one of the alternative strategies towards that goal (Mohamed-Saleem, 1985). This approach also enhances efficient utilization of land, labor and other inputs (Lulseged *et al.,* 1987). Forage legumes enhance soil fertility as they fix N (Diriba *et al.,* 2001) and improve cereal yields when used as green manure (Abebe, 1998). This strategy also improves the yield and nutritive value of harvested crop residues that can be used as important feed resources particularly after grain harvest (Mohamed-Saleem, 1985).

8.3.8.4 Intensification of commercialized forage production

The potential DM yield of Napier grass surpasses that of other tropical grasses (Getenet *et al.,* 2002), which is the reason for its popularity among dairy farmers in Kenya, who have maximized production per unit area of land. Berhanu (2006) found that CH_4 production from cattle fed on grass hay was higher (185.7 ± 13.6 $g.d^{-1}$) than that produced by cattle fed on both Teff straw and supplemented with concentrate mixture (141.8 ± 13.6 $g.d^{-1}$); and Napier grass (124.1 ± 13.6 $g.d^{-1}$). It is therefore suggested that the potential of Napier grass for tropical ruminant feeding is higher in terms of the feed quality and reduction of CH_4 pollution.

In urban and peri-urban areas, the cost of milk production is high. Livestock feed, particularly roughage, which is the most important factor, hampers livestock productivity in general and milk production in particular (Yoseph *et al.,* 1999). Rural-urban linkage is an important strategy to improve the supply of roughage to urban dairy farmers; since rural farmers have a considerable amount of irrigable land for forage production like Napier grass.

8.3.8.5 Physical and chemical treatment of crop residues

Physical treatment of crop residues by chopping had multi-advantages of reducing wastage; increasing intake and digestion thereby increasing feed efficiency (Kessler *et al.,* 1998). In highland areas farmers fed Teff and wheat straw (IPMS, 2004). As cereal straws comprised more than 80 - 90% of the roughages in central highlands, it was of great importance to explore the potential improvement in livestock production through practical and low-cost systems of treating fibrous feed resources physically or chemically. The digestibility of straw is low (40-50%), thus, it does not give much energy to the animals when fed alone. Urea treatment of straw increased the digestibility of crop residues by 50 to 60% (Habib *et al.,* 1991; O'Donovan, 1997), and animals ate 10 to 20% more of the treated straw. Therefore, alternative ways of improving livestock feeds to satisfy the growing demand of animal products without disturbing the environment should be sought, but with efficient utilization of available resources.

8 3.8.6 Community-based livestock breed improvement

High cost of purchasing animals of improved breeds – even when they are easily available - is one of the challenges facing the development of the dairy sector in Ethiopia. In addition, artificial insemination (AI) services are not proceeding as efficient as expected. Therefore, facilitating the provision of improved breeds in community-based breeding programmes such as Bull stations was considered a potential solution for the supply of improved breeds (IPMS, 2004).

In Ethiopia, AI services have been provided by the government institutions alone (IPMS, 2004). These institutions are based in towns; as a result AI technology has not benefited rural framers compared to urban and peri-urban dairy owners. To alleviate the difficulty of providing AI services in rural areas, private AI service delivery systems in rural areas have to be developed. In addition, other technological interventions like estrous synchronization, sexed semen and embryo transfer could be used to increase the reproductive efficiency of livestock.

8.3.8.7 Establishment of proper livestock herd structure

Yoseph *et al.* (2002) reported that in urban and peri-urban dairy farms, the proportion of cows was 50% out of which 36% were lactating cows. The national average of cows in a herd was 42% (Azage and Alemu, 1997). The reason for the high proportion of cows in peri-urban and urban dairy farms (Yoseph *et al.,* 2002) was market orientation targeted to produce more milk to meet the high demand by keeping more cows, since the sale of milk was the major source of income for urban and peri-urban farms. Oxen were widely considered the most important domestic animals in the highlands, because oxen performed nearly all the traction functions for cultivation.

The great reliance on oxen for draught purposes in many highland areas has led to an extraordinary difference in the cattle herd composition between the highlands and pastoral lowland areas, and also in different zones in highland regions. Male cattle outnumbered female cattle, or were nearly of the same proportion, in the highlands (Halderman, 2004). Herd structure is important for economic analysis and recommendation of off-take rate. The maintenance of the right proportion of productive animals in each herd has an implication on grazing pressure and hence on land degradation. It is necessary to reduce the calving interval from the current 580 days to 365 days and to decrease mortality in order to improve the productive and reproductive performance of animals (Azage and Alemu, 1997).

8.3.8.8 Manure management

One of the contributions from livestock is the provision of manure, which is a recyclable organic matter in a mixed crop-livestock farming system; that also adds macro and trace minerals in to the soil, and improves soil texture, moisture holding capacity, water infiltration and soil aeration. Improved moisture holding capacity reduces runoff and prevents crusting of the soil surface (Tesfaye *et al.,* 2004). Small quantities of organic materials can bring about marked improvements in the CEC of soils. However, in the highlands, the livestock population is low and alternative sources of energy so limited that people cannot afford to use livestock dung as organic fertilizer. Instead, the resource-poor people use dung for fuel and/or sell dried dung for extra income (Halderman, 2004).

Tesfaye *et al.* (2004) reported that although farmers in central highlands practice different manure storage methods, some of them clean the barn every day and add fresh dung to a pile stored for over an average period of 240.3 ± 96.44 days. Others put dung in the open either in the backyard or outside the fence beside the main gate, which is the most prevalent method practiced by 72% of the farmers. Lekasi *et al.* (1998) reported that manure stored in the open is of poor quality and environmentally unsafe. Despite its valuable use as fertilizer, manure can also be regarded as a waste and a source of air and water pollution in places where there is over production, or when it is improperly used and stored (Brandjes *et al.,* 1996). Therefore, improved manure management is important for sustainable resource utilization.

8 3.8.9 Marketing

Although the country is rich in livestock resources, inadequate market infrastructure, virtual absence of market information system, absence of market oriented livestock production system, inadequate number of exporting firms with low level of capacities, inadequate knowledge of international trade, low level of quarantine facilities and procedures, prevalence of various animal diseases, repeated bans, excessive cross-border illegal trade and stiff competitions, etc. are the major challenges that hinder the smooth livestock trade in Ethiopia (Belachew and Jemberu, 2003). The development of effective and efficient livestock marketing system is essential to improving and sustaining the livelihoods of livestock producers in Ethiopia, and to promoting environmentally sound natural resource management systems (Halderman, 2004).

8.4 Conclusions

From the sixty-year meteorological data (1951-2009) there was an established increase in rainfall by 2% per annum; and maximum and minimum temperatures by 0.08^{o}C per decade, which amounted to a cumulative temperature increase of 0.5^{o}C in the last decade. The increase in precipitation and temperature favoured the adaption of lowland crops like maize and sorghum to highland agro-ecology. Climate prediction models forecasted that most of the highlands in Ethiopia will remain suitable for cereals like wheat and Teff for the next 50 to 100 years. However, the perception of farmers indicated that they feel more heat and warm weather than they have experienced before. They reported that rainfall is now more erratic or comes late and stops earlier before plants completed their vegetative growth. Therefore, future research on climate change at local level should consider community perceptions, plus intensity of weather data such as frequency and duration of rainfall and relate it with crop water requirements. The research should also give direction on what crop varieties to grow, when to sow, when to harvest and transport, based on the changing climate.

In order to continue to thrive in the future, livestock industries need to anticipate climate change and uncertainties in order to develop adaption strategies. For climate adaption to occur, people need to be aware that climate change is a reality; what the practical impacts will be; and how it will affect businesses. Effective communication will benefit all vulnerable groups and decision makers in adapting to climate change. It is necessary to motivate farmers to change farming practices to adapt to climate change and to use the opportunity to their advantage. Adaptation to climate change has to be accepted and that the uncertainty in climate change should be recognized as unavoidable. It is therefore equally important to ensure that legislation and policies reflect such experiences and incorporate this and other new knowledge into improving adaptive responses over time.

CHAPTER 9:
CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

Livestock sector response to the challenges of environmental change requires formulation of appropriate adaptation and mitigation options. The projected trend of population growth indicates that livestock population will increase tremendously over the next few years and may create conducive conditions for further increase in greenhouse gas emissions. Environment and livestock production systems have multidimensional interactions and challenges because livestock production systems are affected by environmental changes and at the same time they are contributors to the phenomenon.

The use of draught animal power for ploughing, threshing and transport saved tremendous carbon emissions compared to mechanized agriculture. And in addition to carbon release into the atmosphere, mechanized farm operations break down the soil structure to fine particles which contribute to more soil erosion by wind and rain. Mechanization also released carbon monoxide, carbon dioxide and other greenhouse gases from fuel combustion. Hence, draught animal ploughing was a positive farm operation when considered from an environmental point of view.

When comparing the different land uses, grazing was found to have the highest SOC content followed by undisturbed ecology. Grazing lands that were either degraded or fenced off, had high SOC content because of the ability of livestock to add dung and urine to the soil while grazing and their ability of moving organic materials from place to place. As result, it is possible to argue that top layer of grazing lands might get degraded physically but not chemically. The results of this study showed that although livestock was blamed for degrading soil structure and vegetation, this was compensated by adding organic carbon into the soil through dung and urine. In contrasting the different carbon inputs added into the soil, it was found that animal waste and farmyard manure made the highest contribution. This implied that for most of carbon the inputs, livestock products and by-products had a greater place in the carbon sink.

The results showed that different crop and soil management practices increased grain and straw yield in vertisols. Particular combination of leguminous forages with cereal crops improved soil carbon and yield by 40%, while row intercropping of forage legumes with cereals boosted the yield by 30%; and forage grass and legumes mixed cropping improved yield by 40%. All the reviewed literature indicated high biomass production for both the cereal grains and the straw.

Although it was assumed that manure was predominantly used for fertilizer, the bulk of it was actually used as cooking fuel. There was a significant difference in crop response to manure application. Vegetables produced higher yields with manure than chemical fertilizers. Cereals responded more to chemical fertilizers better than to manure. Therefore, combining manure and chemical fertilizers was the best option for the sustainability of crop production in the area.

Some of the limitations to the use of manure as an organic fertilizer were: inadequate manure production, high labour cost, bulkiness, and high transport cost and weed infestation. Manure management systems in the study area were affected by livestock husbandry practices. Only crossbred cattle (5%) were zero-grazed and manure was stored as slurry. Indigenous cattle grazed out in the fields during the day and at night were kept in kraals near homesteads.

There was a substantial loss of nutrients during the day when animals were grazing in the fields through leaching and trampling of dung and urine patches. Indoor or zero grazing of livestock could reduce nutrient losses. The use of manure as fuel in the study area had no significant effect on CO_2 emissions at household or local level, but had a negative impact on soil carbon storage and soil fertility.

Recently, a new dietary strategy for ruminants was proposed in the developed countries to reduce CH_4 emissions by manipulating ruminal fermentation directly by inhibiting methanogens and protozoa or by diverting hydrogen ions away from methanogens.

Heavy metals occur naturally in the earth's crust and their anthropogenic release into the environment causes contamination problems. In the present study, the heavy metal load in the soil was below the hazard level. Although their impact was negligible, this study revealed that contributors of heavy metals could be categorized as factory effluents and animal waste. The role of natural resources such as sediments, rocks and soil particles were insignificant. Anthropogenic factors such as tillage type affected trace mineral concentration to a less extent, and only increased with increasing plough depth.

Results showed that crops like Teff had higher Fe, Cu, Zn, Mn and other micro-nutrients content in their grains because they extracted minerals from the soil. Soil texture had an impact on the mobility of trace minerals, where sandy loam caused a significant nutrient migration to the lower profile due to the porosity of the texture. Discharge of effluents from factories should take into consideration the characteristics of dump sites such as soil texture, organic matter content, soil pH, acidity, waste composition and the concentration of heavy metals. Organic sources were found to be very useful in enhancing macro and micro nutrients availability to plants. In the present study, organic carbon in the soil was very low and could have slowed the availability of trace minerals to plants.

There was an indication of a decline in water resources on per capita basis. The major contributing factors for the decline in water resources were combined pressure of human and animal population on natural resources that led to excessive deforestation, loss of biological diversity, overgrazing, soil degradation and various forms of pollution and contamination. The global climate change has also played a role in the decline of water resources due to the decrease in annual precipitation and rising temperature. Urbanization and economic growth increased the demand for milk and meat, which required additional water use for each unit of animal protein produced. The demand for milk and meat is expected to double over the next 20 years with an annual growth rate of between 2.5 to 4%. Increasing milk and meat production will require more water per unit of the product. This issue has raised concerns of how to meet livestock water requirement based on future human protein demand, population growth, economic prosperity, and climate change.

The intake of water by livestock was influenced by species, breed and physiological state. Under high temperature scenario, water consumption increased by 2.1% for each degree change in temperature. Therefore, with increasing temperature livestock water requirement increased at an increasing rate, which was a danger signal for smallholder farmers who engaged in subsistence farming. However, it was understood that livestock drinking water had an insignificant share of the total water resource depletion compared to water used for feed production and sanitary services.

Livestock sustained water resources in ecosystems by using the little available water in crop residues and metabolic water recharge from the oxidation of feeds. The water recharged through the feeding on crop residues could have been lost through evapo-transpiration, volatilization and trampling. However, if livestock production were based solely on the use of crop residues it would have had a negative consequence on nutrient recycling. Growing fodder legumes and the use of fodder as supplements to crop residues was the most practical and cost-effective method of improving nutritional value of crop residues. Increasing land slope and grazing intensity reduced water infiltration rate into soil and enhanced soil erosion through runoff. Therefore, care has to be taken when selecting ploughing methods based on land slopes and to use different feeding methods to reduce overgrazing.

Livestock contributed to water recharge by increasing soil water retention capacity when manure was used in the fields. Manure increased soil moisture content by 10% both under medium and heavy grazing conditions. Therefore, livestock had a positive water balance role in ecosystems when manure was used for fertilization. Physico-chemical properties such as pH, total dissolved solids, toxic compounds and bacteria have to be below safe limits to maintain the standards of water quality safe for human and livestock consumption.

Sixty-year meteorological data (1951-2009) showed that there was an increasing trend in annual rainfall by 2% per annum and increasing maximum and minimum temperature by 0.08^{o}C per decade. On the average, temperature increased by 0.5^{o}C in the last decade. There was anticipation that increased precipitation and temperature could favour some of the lowland crops like maize and sorghum to adapt to highland agro-ecologies. Climate prediction models forecasted that most of the highlands in Ethiopia will remain suitable for cereals like wheat and Teff for the next 50 to 100 years. However, the perception of farmers indicated that they have experienced more heat and warm weather than ever before. They reported erratic rainfall that come late and stop earlier before crops completed their vegetative growth.

For livestock industries to continue to thrive in the future, farmers need to anticipate these changes, be prepared for uncertainty and develop adaption strategies now. And for adaption to occur, people need to be aware that climate change is real; what the practical impacts would be; and how it would affect businesses in the future. Effective communication is required to help all vulnerable groups and decision-makers to change farming practices and adapt to climate change.

9.2 Recommendations

It is important to study future effects of livestock on the environment based on different technological adaptation options and scenarios that were found suitable to smallholder farmers. Genetic improvement programmes should search for livestock breeds that are adapted to harsh environments that could allow for selection within and between breeds/species for particular environmental conditions. Livestock feed and forage research should seek for programmes that can reduce gas emissions, adapt to harsh environments and also be highly productive per unit of animal product. The use of draught animal power by smallholder farmers for ploughing, threshing and transport should be encourage because it saves tremendous carbon emissions compared to mechanized agriculture.

Livestock played a crucial role in the drainage of water from vertisol soils by pulling broad bed makers for better aeration and nutrient uptake by plants. As a result, improved SOC contributed to the increase in grain and straw yields that led to increased milk and meat production. Therefore, livestock and feedstuffs were key players in improving the soil texture and SOC under smallholder farm management. Livestock production could be considered one of the major agricultural production systems in soil carbon storage. Similarly, livestock production also played an important role in maintaining the eco-system balance through nutrient recycling.

For improved yields and balanced eco-systems manure burning has to be replaced with other alternative energy sources such as bio-gas and kerosene. The largest carbon equivalent emissions were from CH_4 (72.6%), N_2O (24%) and CO_2 (3.4%) which indicated the need to improve livestock and manure management systems under smallholder agriculture. Existing mitigation strategies for CH_4 emissions for dairy farming, which includes the use of high quality forages and increased use of grains, are recommended management practices. In general, change in feeding systems; breed selection, good animal husbandry and improved take-off were also identified as viable options for the reduction of greenhouse gas emissions.

The type of land use had an effect on the level of heavy metal concentration in the soil, particularly Fe which was lower in cultivated soils than uncultivated sites. Therefore, research on essential trace mineral concentration in cereal growing in the highlands is important for the purpose of increasing the yield. The addition of organic matter in the soil is vital for trace elements and general soil fertility improvement. Nutrient recycling through manure application, allowing crop residue to decay on fields, fallowing and rotational cropping has to be practiced to rehabilitate the soil trace mineral content. Minimum and zero tillage have to be practiced to build up trace elements as well.

Alternative water recharging mechanisms such as water recycling, effective soil and water conservation, reforestation and appropriate water use have to be sought for. Family planning has to be integrated with water resource use and management programmes. In addition, the water recharging schemes have to integrate the planning and implementation of water resource with community participation.

In the current study, the concentrations of some of the chemicals in the water bodies were well above the standard limits. Therefore, development programmes and environmental groups have to find ways of maintaining the protected water bodies and improvising the quality of those water bodies that are contaminated by excessive chemical load. Future research on climate change at the local level should consider community perceptions, intensity of weather data such as frequency, beginning and ending of rainfall, and relate it with crop water requirements. The research should give directions on what crop varieties to grow, when to sow or harvest and transport, based on the changing climate. Adaptation to climate change has to be accepted and that the uncertainty in climate change should be recognized as unavoidable. It is, therefore, equally important to ensure that legislation and policies reflect such experiences and incorporate this and other new knowledge into improving adaptive responses over time.

REFERENCES

Abate, T. and Mohamed-Saleem, M A. 1992. Cropping systems for vertisols of the Ethiopian highlands. In: Reports and papers on the management of vertisols (IBSRAM/AFRICALAND). Reports of the annual review meeting held in Nairobi Kenya, 4-6 March 1991. Network document 1. International Board for Soil Research and Management, Nairobi, Kenya. pp. 55-66.

Abate, T., Mohamed-Saleem, M.A., Tekalign, M. and Tirkessa, D. 1993. Grain, fodder and residue management. In: M. Takalign, A. Abiye, K.L. Srivastya, and D. Asgelil, D. (Eds) Improved management of vertisols for sustainable crop-livestock production in the Ethiopian highlands: Synthesis report 1986-92. Technical Committee of the Joint Vertisol Project, Addis Ababa, Ethiopia. pp. 103-137.

Abebe, Y. 1998. Evaluation of the contribution of scattered *Cordia africana* Lam. trees to soil properties of cropland and rangeland ecosystems in western Oromia, Ethiopia. M.Sc. Thesis, Swedish University of Agricultural Sciences, Sweden.

Abiye, A., Ferew, K. 1993. Modifying the traditional plough (marseha) for better management of vertisols. In: M. Takalign, A. Abiye, K.L. Srivastya, and D. Asgelil. (eds). Improved management of vertisols for sustainable crop-livestock production in the Ethiopian highlands: Synthesis report 1986-92. Technical Committee of the Joint Vertisol Project, Addis Ababa, Ethiopia. pp. 85-101.

Abiye, A. and Mohamed-Saleem. 1998. Effect of different cropping options on plant-available water of surface-drained vertisols in the Ethiopian highlands. *Agricultural Water Management,* 36 (2): 111-120.

Adam, W.A. 1973. The effect of organic matter on the bulk and true densities of some uncultivated podzolic soils. *Journal of Soil Science,* 24: 10-17.

Ahmed, M.M., Ehui, S. and Yemeserach, A. 2003. Dairy Development in Ethiopia. Socio-economics and Policy Research Working Paper 58. ILRI, Nairobi, Kenya, pp. 47.

Alemayehu, M. 2005. Feed Resources Base of Ethiopia: Status, limitations and opportunities for integrated development. In the *Proceedings of the 12th Annual Conference of the Ethiopian Society of Animal Production*, pp. 251-259.

Alemayehu, M. 1997. Conservation based forage development for Ethiopia. Self-help Development International and Institute for Sustainable Development, Addis Ababa, Ethiopia.

Alemayehu, M. 1985. Feed resources in Ethiopia. A paper presented at the workshop on animal feed resources for small-scale livestock producers, 11-15 November 1985, Nairobi, Kenya.

Alemu, Z.G. 2002. How successful the agricultural development-led industrialization strategy will be by leaving the existing landholding system intact? Economic Focus, *Ethiopian Economic Association*, 4 (4): 16-20.

Alloway, B.J. 1994. Toxic metals in soil-plant systems. Chichester, UK: John Wiley and Sons.

Altizer, S., Bartel, R. and Han, A.B. 2011. Animal migration and infectious disease risk. *Science,* 331 (6015): 296-302.

Amare, H. 2007. Metal concentration in vegetable grown in northern Addis Ababa, Ethiopia. M Sc. Thesis, in partial fulfillment of the requirement for the degree of Master of Science in Environmental Science. Addis Ababa University School of Graduate Study. pp.79.

Amare. G. 1980. Agro-climates and agricultural systems in Ethiopia, *Agricultural Systems,* 5: 39-50.

Anderson, J. and Bausch, C. 2006. Climate change and natural disasters: Scientific evidence of a possible relation between recent natural disasters and climate change. Policy Brief for the EP Environment Committee, IP/A/ENVI/FWC/2005–35. Available at<http://www.europarl.eu.int/comparl/envi/pdf/externalexpertise/ieep_61eg/naturaldisas ters.pdf>. Accessed on 13 April 2013.

Antoniadis, V. 1998. Heavy metal availability and mobility in sewage sludge treated soils. PhD Thesis. The University of Reading. Department of Soil Science. UK.

Association of Official Agricultural Chemists. 2000. Official methods of analysis, 17th Ed. Gaithersburg, Maryland, USA.

American Society of Agronomy. 2005. Micrometeorology in agricultural system, *American Society of Agronomy*, Agronomy Monograph No. 47. Inc. Madison, Wisconsin, USA.

Asnakew, W. 1988. Physical properties of Ethiopian Vertisols. In: S.C. Jutzi, I. Haque, J. McIntire and J.E.S. Stares, (Eds). Management of vertisols in sub-Saharan Africa. Proceedings of a conference held at ILCA, Addis Ababa Ethiopia 31 August - 4 September 1987. pp. 111-123.

Asres, K. 2003. Impact of incentive system on soil and water conservation activities in Ambasel area, south Wollo, Ethiopia, MSc. Thesis, Alemaya University, pp. 104.

Association of Official Agricultural Chemists. 2000. Official methods of analysis. Association of Official Agricultural Chemists, Washington, D.C.

Awulachew, S. B., Merrey,D. J., Kamara,A. B., Van Koppen, B., Penning de Vries, F., Boelee, E. and Makombe, G. 2005. Experiences and opportunities for promoting Small-scale/ micro irrigation and rainwater harvesting for food security in Ethiopia. Working Paper 98. IWMI, Colombo, Sri Lanka. 86 pp.

Azage, T. 2002. Escape from Poverty: The case of Ada'a-Liben Woreda dairy and dairy products marketing association, Ethiopia. Proceedings of the international workshop on fostering rural economic development through agriculture-bed enterprises and services, held in GTZ-Haus, Berlin, Germany, 20 – 22 Nov, 2002. www.gtz.de/agro-based-development.

Azage, T. and Alemu, G. 1997. Prospects for peri-urban dairy development in Ethiopia. *Proceedings of the 5th National Conference of the Ethiopian Society of Animal Production*, May 1997, Addis Ababa, Ethiopia. pp. 28-39.

Badada, B. 2000. Socio-economic scenarios for Ethiopia. Unpublished report submitted to NMSA under the GEF/UNDP supported climate change enabling activities project (ETH /97/G31) of Ethiopia.

Barbehenn, R.V., Chen, Z., Karowe, D.N. and Spickard, A. 2004. C_3 grasses have a higher nutritional quality than C_4 grasses under ambient and elevated atmospheric CO_2. *Global Change Biology*, 10: 1565-1575.

Barreto, R., Madari, B.E., Maddock, J.E.L., Machado, P.L.O.A., Torres, E., Franchini, J. and Costa, A.R. 2009. The impact of soil management on aggregation, carbon stabilization and carbon loss as CO^2 in the surface layer of a Rhodic Ferralsol in Southern Brazil., *Agriculture, Ecosystem and Environment*, 132(3-4): 243-251.

Bekele, S. 1991. Crop-livestock interactions in the Ethiopian highlands and effects on sustainability of mixed farming: A case study from Ada district. M.Sc. Thesis. Agricultural University of Norway. Oslo, Norway.

Belachew, H. and Jemberu, E. 2003. Challenges and opportunities of livestock marketing in Ethiopia. Challenges and opportunities of livestock marketing in Ethiopia: *Proceedings of the 10th Annual Conference of the ESAP* held in Addis Ababa, Ethiopia, August 21-23, 2003. pp. 1-14.

Berhanu, D. 1985. The Vertisols of Ethiopia, their characteristics, classification and management. In: Fifth Meeting of the eastern African sub-committee for soil correlation and land evaluation, Wad Medani, Sudan, 5-10 December 1983. World Soil Resources Report No. 56. FAO, Rome. pp. 31-54.

Berhanu, K. 2006. Methane Production and Energy Partitioning in *Bos indicus* cattle (Boran breed) fed on selected tropical feeds in Ethiopia. M.Sc. Thesis, School of Graduate Studies, Haramaya University.

Beruk, Y. 2000. Livestock feed resource status of Afare region. In: Pastoralism and agro-pastoralism, which way forward? Proceeding of the 8th Annual conference of ESAP (Ethiopian Society of Animal Production).24-26 August 2000, Addis Ababa Ethiopia. pp. 35-43.

Beyene, D. 1988. Soil fertility research on some Ethiopian Vertisols. In: Jutzi, S. C., Haque, I., McIntire, J. and Stares, J. E. S. (Eds), Management of Vertisols in sub-Saharan Africa Proceedings of a Conference held at ILCA, Addis Ababa, Ethiopia, 31 August to 4 September 1987. pp. 223-231.

Birenesh, A. 2007. Assessment of downstream pollution profiles of Awassa textile effluent along Tikur Wuha River using physico-chemical and macro-invertebrate indicators. M.Sc Thesis. Addis Ababa University. School of Graduate Studies Environmental Science. Addis Ababa, Ethiopia. 90 pp. http://etd.aau.edu.et/dspace/bitstream//123456789/225

Bojo, J. and Casells, D. 1995. Land degradation and rehabilitation in Ethiopia; A reassessment. AFTES working paper 17.World Bank Washington D.C.

Bouyoucos, G.J. 1951. A recalibration of the hydrometer method for the analysis of soils. *Agronomy of Journal,* 43(9): 434-437.

Bouyoucos, G.J. 1951. A recalibration of the hydrometer method for the analysis of soils. *Agronomy of Journal,* 43(9): 434-437.

Brandjes, P.J., de Wit, J. and van der Meer, H.G. 1996. Environmental impact of animal manure management, H. Van Keulen International Agriculture Centre, Wageningen, The Netherlands.

Burke, I.C., Lauenroth, W.K. and Coffin, D.P. 1995. Soil organic matter recovery in semiarid grasslands: implications for the conservation reserve program. *Ecological*

Monographs, 5: 793-801.

Canadian Council of Resource and Environment Ministers. 1987. Canadian water quality guidelines. Prepared by the task force on water quality guidelines.

Carbon Dioxide Information Analysis Center. 2007. http://cdiac.ornl.gov/pns/current_ghg.html. Accessed on July 7 2013.

Chaney, R.L. and Ryan, J.A. 1993. Heavy metals and toxic organic pollutants in MSW-compost: Research results on phyto-availability, bio-availability, fate, etc. In: Hoitink, H.A.J. and Keener, H.M. (Eds.) Science and engineering of composting: Design, environmental, microbiological and utilization aspects. Renaissance Publications, Worthington, Ohio, pp. 451-506.

Chapman, H.D. 1965. Cation exchange capacity. In: C.A. Black (Ed). Methods of Soil Analysis, *American Society of Agronomy*. Madison, WI.

Cheng, S. 2007. Heavy metal pollution in China: Origin, pattern and control: a state-of-the-art report with special reference to literature published in Chinese journals. *Environmental Scientific Pollution Research*, 14: 489–489.

Christensen, B.T. 1996. Matching measurable soil organic matter fractions with conceptual pools in simulation models of carbon turnover: Revision of model structure. In: D.S. Powlson, P. Smith, and J.U. Smith (Eds.). Evaluation of Soil Organic Matter Models. NATO, ASI Series I, Vol.38. Springer-Verlag, Berlin

Christensen, J.B., Jensen, D.L. and Christensen, T.H. 1996. Effect of dissolved organic carbon on the mobility of cadmium, nickel and zinc in leachate polluted groundwater. *Water Research*, 30: 3037-3049.

Cline, W.R. 2007. Global warming and agriculture: Impact estimates by country, Washington DC: Centre for global development and Peterson institute for international economics.

Constable, M. 1984. Resources of rural development in Ethiopia: Ethiopian Highlands. Reclamation study. Working paper 17, FAO and Ministry of Agriculture, Addis Ababa. Ethiopia.

Costa, J.L., Massone, H., Martnez, D., Suero, E.E., Vidal, C.M. and Bedmar, F. 2002. Nitrate contamination of rural aquifer and accumulation in the unsaturated zone. *Agricultural water management*, 57(1): 33-47.

Central Statistical Authority of Ethiopia. 2010. Agricultural sample survey report on area and production of crops, *Statistical Bulletin* Vol. IV, No. 446, Addis Ababa, Ethiopia.

Cunningham, E.P. 1995. Global impact domain: Animal genetic resources. Working document livestock and the environment: Finding a balance. FAO/World Bank/USAID. Rome.

David, H. 2009 (Unpublished). Water requirements of ruminants. *Animal Agriculture Consulting*, Inc. Amarillo, Texas 79159.

De Hann, C.H., Steinfeld, H. and Blackburn, H. 1997. Livestock and the environment: Finding a balance, Suffolk, UK, WREN media.

De Hann, C.H., Steinfeld, H. and Blackburn, H. 1998. Livestock-Environment Interaction: issues and options. Report of a study. WREN media, Fressingfield, EYE, Suffolk, IP21 5SA United Kingdom.

Delgado C., Rosegrant, M., Steinfeld, H., Ehui, S. and Courbois, C. 1999. Livestock to 2020: The Next Food Revolution. 2020 Brief 61. A 2020 Vision for Food, Agriculture, and the Environment. IFPRI, Washington, USA.

Deressa, T. 2007. Measuring the economic impact of climate change on Ethiopian agriculture: Ricardian approach. World Bank Policy Research Working Paper No. 4342, World Bank, Washington DC.

Deressa, T. and Hassan, R. M. 2009. Economic Impact of Climate Change on Crop Production in Ethiopia: Evidence from Cross-Section Measures, *Journal of African Economies*, 18(4): 529-554.

Diao, X., Nini, P. A., Guatam, M., Keough, J., Chamberlain, J., You, L., Puetz, D., Resnick, D. and Yu, B. 2005. Growth options and poverty reduction in Ethiopia: A spatial economy-wide model analysis for 2004 to 2015, DSG Discussion Paper No.20 IFPRI, Washington D.C.

Diriba, G., Lemma, G. and Adane, H. 2001. Grain and forage yield responses of maize genotypes intercropped with *lablab purpureus* under Bako condition, Western Ethiopia. Livestock in food security –Roles and contributions. Proceedings of the 9th annual conference of the ESAP held in Addis Ababa, Ethiopia, August 30-31, 2001 DIVA-GIS website (http://www.diva-gis.org). Accessed September, 2013.

Dolberg, F. and Finlayson, P. 1995. Treated straw for beef production in China. *World Animal Review,* 82: 14-24.

Dowdy, R.H. and Volk, V.V. 1983. Movement of heavy metals in soils. In: Chemical Mobility and Reactivity in Soil Systems. *Soil Science Society of America and American Society of Agronomy,* Madison, pp. 229-240.

During, R. A., Ho, B. T. and Gath. S. 2003. Sorption and bioavailability of heavy metals in long – term differently tilled soils amended with organic wastes. *Science and Total Environment,* 313: 227–234.

Easterling, W.E., Aggarwal, P.K., Batima, P., Brander, K.M., Erda, L., Howden, S.M., Kirilenko, A., Morton, J., Soussana, J.F., Schmidhuber, J. and Tubiello, F.N. 2007. In: M.L. Parry, O.F. Canziani, J.P. Palatikof, P.J. van der Linden and C.E. Hanson (eds).Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, United Kingdom.

El-Hassanin, A.S., Labib, T.M. and Dobal, A.T. 1993. Potential Pb, Cd, Zn, and B contamination of sandy soils after different irrigation periods with sewage effluent. *Water, Air and Soil Pollution,* 66: 239-249.

Emmerich, W.E., Lund, L.J., Page, A.L. and Chang, A.C. 1982. Movement of heavy metals in sewage sludge-treated soils. *Journal of Environmental Quality*, 11: 174-178.

Endale, K. 2011. Fertilizer Consumption and Agricultural Productivity in Ethiopia. Ethiopian Development Research Institute, Working Paper 003 Addis Ababa, Ethiopia

European Commission. 2008. European Commission Regulation No. 629/2008 of 2 Jul 2008 amending Regulation No 1881/2006 setting maximum levels for certain contaminants in foodstuffs. Available at: www.fsai.ie/uploadedFiles/CommissionRegulation_EC_No_629_2008.pdf. Accessed 6 January 2010.

European Commission. 2006. European Commission Regulation No.1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs. Available at: eurlex.europa.eu/LexUriServ/site/en/oj/2006/l_364/l_36420061220en00050024.pdf. Accessed 6 December 2010.

Everitt, B.S., Landau, S. and Leese, M. 2001. Cluster Analysis, Fourth edition, Arnold.

Falloon, P. and Smith, P. 2002. Simulating SOC changes in long-term experiments with Roth, C. and Century: a model evaluation for a regional scale application. *Soil Use Manual,* 18: 101-111.

Food and Agricultural Organization of United Nations. 2012. FAOSTAT and FAOMAP, World agriculture information center. FAO, Rome, Italy.

Food and Agricultural Organization of United Nations. 2011. AQUASTAT http://www.fao.org/nr/water/aquastat/dbase/index.stm. Accessed January 2011.

Food and Agricultural Organization of United Nations. 2006. Livestock's Long Shadow: environmental issues and options, LEAD website: http://www.virtual centre.org/en/dec/toolbox/homepage.htm/ viewed on 8 March 2013.

Food and Agricultural Organization of United Nations. 2004. Carbon sequestration in dry lands. Food and Agricultural Organization, Rome, www.fao.org/docrep/007/y5738e/y5738e0c.htm> Viewed on 8 March 2013.

Food and Agricultural Organization of United Nations. 2002. Harvesting carbon sequestration through land-use change: A way out of rural poverty? In: The state of food and agriculture, Rome, ftp://ftp.fao.org/docrep/fao/004/y6000e/y6000e10.pdf. Viewed on 8 March 2013.

Food and Agricultural Organization of United Nations. 2001. Soil carbon sequestration for improved land management. Food and Agricultural Organization, World Soil Resources Report No. 96. Rome, ftp://ftp.fao.org/agl/agll/docs/wsrr96e.pdf. Viewed on 8 March 2013.

Food and Agricultural Organization of United Nations. 2000. Two Essays on Climate Change and Agriculture: A developing country perspective. FAO Economic and Social Development Unit, No. 145 Rome, Italy.

Food and Agricultural Organization of United Nations. 1999. Prevention of land degradation, enhancement of carbon sequestration and conservation of biodiversity through land-use change and sustainable land management with a focus on Latin America and the Caribbean. Rome.

Food and Agricultural Organization of United Nations. 1998. Crop evapotranspiration – guidelines for computing crop water requirements. FAO, Rome.

Fernandez-Rivera, S., Williams, T. O., Hiernaux, P. and Powell, J. M. 1995. Faecal excretion by ruminants and manure availability for crop production in semi-arid West Africa. In: J. M. Powell, S. FernaÂndez-Rivera, T. O. Williams, and C. Renard (Eds). Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa. Vol II: Technical papers, In Proceedings of an international conference held in Addis Ababa, Ethiopia, 22 to 26 November 1993. ILCA, Addis Ababa.

Famine Early Warning System Network. 2003. Ethiopian network on food security 5/20/2003. Famine Early Warning System Network of USAID. Available at http://www.fews.net/current/monthlies/report/?submit=y&m=1000918&f=et&l=en Accessed 28 April 2008.

Fischer, G. and Van Velthuizen, H.T. 1996. Climate change and global agricultural potential project: A case study of Kenya. International Institute for Applied Systems Analysis, Luxemburg, Austria.

Fisseha, I. 2002. Metals in leafy vegetables grown in Addis Ababa and toxicological implications. *Ethiopian Journal of Health Development*, 16 (3): 295-302.

Fisseha, I. 1998. Comparative study on soil pollution with toxic substances on farm lands close to old and new industrial sites in Ethiopia, *Bulletin of the chemical society of Ethiopia*, 12: 105-112.

Fisseha, I. and Olsson, M. 2004. Land degradation in Addis in Ababa due to Industrial and Urban Development. *Ethiopian Journal of Developmental Research*, 26 (1):77-100.

Forstner, V. 1993. Riverine and estuarine sedimentation of pollutants and leaks from sludges and wastes- Analystical, prognostic and remedial approaches. *Land Degradation and Rehabilitation,* 4: 281-296.

Franzluebbers, A.J., Stuedemann, J.A., Schomberg, H.H. and Wilkinson, S.R. 2000. Soil organic carbon and nitrogen pools under long-term pasture management in the southern Piedmont USA. *Soil Biology and Biochemistry,* 32: 469-478.

Fredu, N., Mathijs, E., Deckers, E. and Tollens, E. 2009. Rural livestock asset portfolio in northern Ethiopia: A macroeconomic analysis of choice and accumulation. Contributed Paper prepared for presentation at the International Association of Agricultural Economists Conference, Beijing, China.

Gaughan, J. B., Lacetera, N., Valtorta, S. E., Khalifa, H. H., Hahn, G. L. and Mader, T. L. 2009. Adaptive responses of domestic (farm animals) to climate challenges. In: G.R. McGregor, R. de Dear, K.L. Ebi, D. Scott, S. Sheridan and M.D. Schwartz (Eds). Biometeorology for Adaptation to Climate Variability and Change, 1 Ed: 131-170 Germany: Springer.

Getachew, F. and Gashaw, G. 2001. The Ethiopian Dairy Development. A Draft Policy Document, MOA/FAO, Addis Ababa, Ethiopia.

Getenet, A. 2003. Effect of manure and nitrogen fertilization on the establishment, herbage yield and seed productivity of perennial grasses' Challenges and opportunities in livestock marketing in Ethiopia, Ethiopian Society of Animal Production, Addis Ababa (Ethiopia). In Proceedings of the Annual Conference of Ethiopian Society of Animal Production, Addis Ababa, 21-23 Aug 2003.- pp. 245-253.

Getnet, A., Abreham, G., Fekede, F. and Tadesse, T. 2002 . On-farm performance of forage crops and assessment of natural pasture productivity in west Shewa zone. Proceedings of a workshop on client oriented research held on 16-18 Oct 2001, Holetta Research Center, Ethiopia.

Generations Integrated Rural Development Consultants. 2007. UN Water/WWAP/2006/7. National water development report for Ethiopia, December 2004. Final MOWR UNESCO GIRDC.

Gray, C. and Mueller, V. 2011. Drought and Human Migration in Rural Ethiopia. *World Development* 40 (1): 134–145.

Gryseels, G. 1988. Role of livestock on mixed smallholder farms in the Ethiopian highlands: A case study from the Baso and Worena weredas near Debre Berhan.PhD thesis, Wageningen Agricultural University, The Netherlands. 249 pp.

Guisquiani, P.L., Gigliotti, G. and Businelli, D. 1992. Mobility of heavy metals in urban waste-amended soils. *Journal of Environmental Quality,* 21: 330-335.

Gupta, U. C. and Gupta, S. C. 1998. Trace element toxicity relationships to crop production and livestock and human health: Implication for management, *Community Soil Science and Plant Analysis,* 29: 1491–1522.

Habib, G.S., Basit A. S., S., Wahidullah, J. G. and Ghufranullah, 1991. Importance of Urea Molasses blocks on animal production, Pakistan. International atomic energy agency, international symposium on nuclear and related techniques in animal production and health, Vienna, Austria, 15-19 April 1991.

Hadera, G. 2001. Role of livestock in food security and food self-sufficiency in the Highland production system: Livestock in Food Security – Roles and Contributions Proceedings of the 9th annual conference of the Ethiopian Society of Animal Production (ESAP) held in Addis Ababa, Ethiopia, August 30-31, 2001.

Haile Sellassie, A., Peden,D., Gebreselassie,S., Ayalneh, W., Amede, T. and Girma,T. 2007. Farm scale livestock management and land use decisions in the upper Blue Nile basin: implication for spatial variability of livestock water productivity. ILRI (International Livestock Research Institute), Addis Ababa, Ethiopia.

Haile Sellassie, A., Peden, D., Negash, F. and Gidyelew, T. 2006. Sediment sources and sinks in the Gumera watershed, Ethiopia: implications for livestock water productivity in the Nile River Basin. *Proceedings of Nile basin forum, Nile Basin Initiative*, Addis Ababa.

Halderman, M. 2004. The Political Economy of Pro-Poor: Livestock Policy-Making in Ethiopia PPLPI Working Paper No. 19, FAO, PPLPI.

Hamon, R.E., Lorenz, S.E., Holm, P.E., Christensen, T.H. and McGrath, S.P. 1995. Changes in trace metal species and other components of the rhizosphere during growth of radish. *Plant and Environment,* 18: 749-756.

Hansen, P. J. 2004. Physiological and cellular adaptations of Zebu cattle to thermal stress. *Animal Reproduction Science*, 82/83 (1): 349-360.

Hansen, M.N., Henriksen, K. and Sommer, S.G. 2006. Observations of production and emission of greenhouse gases and ammonia during storage of solids separated from pig slurry: effects of covering. *Atmospheric Environment*, 40: 4172-4181.

Haque, I., Mesfin, A., Tekalign, M. and Asgelil, D. 1993. Nutrient management. In: Takalign, M., Abiye, A., Srivastya, K.L., Asgelil, D. (Eds). Improved management of vertisols for sustainable crop-livestock production in the Ethiopian highlands*:* Synthesis report 1986- 92. Technical committee of the joint vertisol project, Addis Ababa, Ethiopia. pp. 51-73.

Harmsen, K. 1977. Behaviour of heavy metals in soils. Centre for agricultural publishing and documentation, Wageningen, pp. 5-171.

Harris , F. and Yusuf, M.A. 2001. Manure management by smallholders farmers in the Kano close-settled zone, Nigeria. *Experimental Agriculture*. Cambridge University Press, 37: 319-332.

Hassan, R. M. 2010. Implications of Climate Change for Agricultural Sector Performance in Africa: Policy Challenges and Research Agenda. Journal of African Economies, 19 (AERC Supplement): 77-105.

Haynes, R. J. 2005. Labile organic matter fractions as central components of the quality of agricultural soils, an overview. *Advanced Agronomy*, 85: 221–268.

He, Z., Yang, X.E. and Stoffella, P.J. 2005. Trace elements in agro-ecosystems and impacts on the environment. *Journal of Trace Elements Medical Biol*ogy, 19: 125–140.

Hernanz, J.L., Sanchez-Giron, V. and Navarrete, L. 2009. Soil carbon sequestration and stratification in a cereal/leguminous crop rotation with three tillage systems in semiarid condition, *Agriculture, Ecosystems and Environment,* 133 (1-2): 114-122.

Hickmen, J.E., Havlikova, M., Kroeze, C. and Palm, C.A. 2011. Current and future nitrous oxide emissions from African agriculture. Current Opinion in Environmental Sustainability, 3: 370-378.

Higgins, A.J. 1984. Environmental constrains of land application of sewage sludge. *American Society of Agricultural Engineers*, 27: 407-414.

Hijmans, R.J., Guarion,L., Jarvis, A.,O'Brien, R., Matthur, P., Bussink,C., Cruz, M., Barrantes, I. and Rojas, E. 2005. DIVA-GIS Version 5.2. Manual. International plant genetic resource institute, the International Potato Center, Lima Peru.

Hoben, A. 1995. Paradigms and politics: the cultural construction of environmental-policy in Ethiopia. *World Develop*ment, 23: 1007–1021.

Hoffmann, I. and Gerling, D. 2001.Farmers' management strategies to maintain soil fertility in a remote area in northwest Nigeria. *Agriculture, Ecosystems and Environment,* 86: 263-275.

International Livestock Centre for Africa. 1994. Improving livestock production in Africa: Evolution of ILCA's Programme 1974-1994. ILCA, Addis Ababa, Ethiopia. pp. 233.

International Livestock Research Institute. 2002. Increasing water-use efficiency for food production through better livestock management. ILRI, Nairobi, Kenya.

International Livestock Research Institute. 2000. Handbook of Livestock Statistics for Developing Countries. ILRI, Nairobi, Kenya.

Inter-governmental Panel on Climate Change. 2007. Climate Change 2007: In: S. Solomon, D. Quin, M. Manning, Z. Chen, M. Marquis, K. Avertyt, M. Tignor and H. Miller (Eds).The Physical Science Basis, Working Group 1 Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge and New York.

Inter-governmental Panel for Climate Change. 2001. Climate change 2001: Impacts, adaptation and vulnerability. IPCC Third Assessment Report. UK, Cambridge University Press.

Intergovernmental Panel for Climate Change. 1996. Revised 1996, IPCC Guidelines for National Greenhouse Gas Inventories, IPCC, Mexico City.

Improving Productivity and Market Success for Ethiopian Farmers. 2004. Ada Liben Woreda Diagnostic Survey, ILRI (International Livestock Research Institute), Addis Ababa, Ethiopia. pp.74.

International Union for the Conservation of Nature. 1990. Ethiopian National Conservation Strategy. Phase I Report. IUCN. Addis Ababa, Ethiopia.

Jackson, H.L. and Mtengeti, E.J. 2005. Assessment of animal manure production, management and utilization in the Southern Highlands of Tanzania. *Livestock Research for Rural Development. Vol. 17, Article No.110.* Retrieved March 19, 2013, from http://www.lrrd.org/lrrd17/10/jack17110.htm.

Jahnke, H. 1982. Livestock Production Systems and Livestock Development in Tropical Africa. Kiel, Germany: Kieler Wissenschaftsverlag Vauk.

Jardine, P.M., Dunnivant, F.M., Selim, H.M. and McCarthy, J.F. 1992. Comparison of models for describing the transport of dissolved organic carbon in aquifer columns. *Soil Science Society of America Journal*, 56: 393-401.

Jenkinson, D.S., Andrew, S.P.S., Lynch, J.M., Goss, M.J. and Tinker, P.B. 1990. The turnover of organic carbon and nitrogen in soil. Phil. Trans. R. Soc. Lond. B., 29: 361-369.

Johnson, D.E., Phetteplace, H.W. and Seidl, A .F. 2002. Methane, nitrous oxide and carbon dioxide emissions from ruminant livestock production systems. In: J. Takahashi and B.A. Young (Eds.), GHG and animal agriculture. *Proceeding of the 1st international conference on GHG and animal agriculture,* Obihiro, Japan, November 2001.

Jutzi, S. C., Anderson, F. M. and Abiye, A. 1987. Low cost modifications of the traditional Ethiopian tine plow for land shaping and surface drainage of heavy clay soils: Preliminary results from on-farm verification. ILCA Bulletin27:28-31. ILCA, Addis Ababa, Ethiopia.

Kabata-Pendias. 2007. A. Trace Elements in Soils and Plants. 3rd ed. CRC Press, Boca Raton, FL, USA.

Kahsay, B. 2004. Land use and land cover changes in the central highlands of Ethiopia: The case of Yere Mountains and its surroundings, M.Sc. Thesis, Addis Ababa University. pp.147.

Kapkiyai, J.J., Karanja, N.K., Qureshi, J.N., Smithson, P.C. and Woomer, P.L. 1999. Soil organic matter and nutrient dynamics in a Kenyan nitrisol under long-term fertilizer and organic input management. *Soil Biology and Biochemistry*, 31: 1773-1782.

Kessler, R.W., Becker, U., Kohler, R. and Goth. B. 1998. Steam explosion of flax- a superior technique for upgrading fiber value. *Biomass Bio-energy*, 14(3): 237-249.

Ketema, S. 1997. Tef. *Eragrostis tef* (Zucc.) Trotter. Promoting the Conservation and Use of Underutilized and Neglected Crops. 12. Institute of plant genetics and crop plant research, Gatersleben/Int. plant genetic resources institute, (IPGRI) Rome, Italy.

Kroeze, C., Mosier, A. 2002. Progress in source strength estimates of nitrous oxide (N2O). In van Ham, J; Baede, A.P.M.; Guicherit, R.; Williams-Jacobse, J.G.F.M. (Eds.) NON-CO2 Greenhouse gases: Scientific understanding, control options and policy aspects. *Proceedings of the Third International Symposium.* Maastricht, The Netherlands 21-23 January 2002. pp. 29-33.

Külling, D.R., Menzi, H., Sutter, F., Lischer, P. and Kreuzer, M. 2003. Ammonia, nitrous oxide and methane emissions from differently stored dairy manure derived from grass-and hay-based rations. *Nutrient Cycling Agro-ecosystems*, 65: 13-22.

Kurihara, M., Nishida, T., Purnomoadi, A., Shibata, M. and Terada, F. 2002. The prediction of methane conversion rate from dietary factors In: Greenhouse Gases and Animal Agriculture. (Eds). J. Takahashi and B. A. Young, Elsevier, Amsterdam. pp. 171-174.

Lal, R. 2006. Enhancing crop yields in developing countries through restoration of soil organic matter. *Land Degradation and Development*, 17:197–209.

Lal, R. 2004. Soil carbon sequestration impacts on global climate change and food security. Science, 304 (5677): 1623-1627. www.sciencemag.org. Viewed on 8 March 2013.

Lal, R. 2002. Carbon sequestration in dry land ecosystems of west Asia and North Africa *Land Degradation and Development*, 13:45 - 59.

Lal, R. 2001. Potential of desertification control to sequester carbon and mitigate the greenhouse effect. Climate *Change*, 51: 35 - 92.

Lavado, R.S., Claudia, P. C.A. and Alvarez, R. 200**1.**Nutrient and heavy metal concentration and distribution in corn, soybean and wheat as affected by different tillage systems in the Argentine Pampas.

Lee, B.D., Carter, B.J., Basta, N.T. and Weaver, B. 1997. Factors influencing heavy metal distribution in six Oklahoma benchmark soils. *Soil Science Society of America Journal*, 61: 218-223.

Lekasi, J. K., Tanner, J.C., Kimani, S.K. and Harris, P.J.C. 1998. Manure management in the Kenya Highlands: Practices and potential. Natural Resources Systems Programme, Department for International Development and Henry Doubleday Research Association, UK.

Lelieveld, J., Crutzen, P.J. and Bruhl, C. 1993. Climate effects of atmospheric methane. *Chemosphere*, 26: 739-768.

Lemma, B., Kleja, D.B., Nilsson, I. and Olsson, M. 2007.Soil carbon sequestration under different exotic tree species in the southwestern highlands of Ethiopia.

Lemus, R. and Lal, R. 2005. Bioenergy crops and carbon sequestration: critical reviews in plant sciences, 24: 1-21.

Luke, G.J. 1987. Consumption of water by livestock. Resource management technical report No. 60. Department of Agriculture Western Australia.

Lulseged, G., Gebre-Medhin, H. and Tadesse, T. 1987. Undersowing of Forage Crops in Cereals: Some Achievements. Proceeding of 1st National Livestock Improvement Conference. Addis Ababa, Ethiopia. pp. 151-154.

Lund, L.J., Page, A.L. and Nelson, C.O. 1976. Movement of heavy metals below sewage disposal ponds. *Journal of Environmental Quality*, 5: 330-334.

Lupwayi, N. Z., Girma, M. and Haque, I. 2000. Plant nutrient contents of cattle manures from small-scale farms and experimental stations in Ethiopian highlands. *Agriculture, Ecosystems and Environment*, 78: 57-63.

Manly, B.F.J. 2005. Multivariate Statistical Methods: A Primer, 3rd Edition, Chapman and Hall.

Mann, L.K. 1986. Changes in soil carbon after cultivation. *Soil Science,* 142: 279-288.

Manning, P. 2005. Migration in World History. Routledge. ISBN 0415311470.

Marksoe, T. 2007. Personal Communication. FAO, Egypt.

Mateos, M. 2003. Water and the environment in Ethiopia. In: McCornick P.G., Kamara A.B. and Tadesse G. (Eds). Integrated water and land management research and capacity building priorities for Ethiopia, *Proceedings of a MoWR/EARO/IMWI/ILRI international workshop* held at ILRI, Addis Ababa, Ethiopia, 2–4 December 2002.

Mekete, B. 2008. Integrating Livestock Production into Water Resources Development: Assessment on livelihood resilience and livestock water productivity at Alewuha and Golina rivers. M.Sc. Thesis. Hawassa University. Department of Animal and Range Science, Hawassa College of Agriculture, School of Graduate Studies. Hawassa, Ethiopia.

Mendelssohn, R. and Dinar, A. 1999. Climate Change, Agriculture, and Developing Countries: Does adaptation matter? *The World Bank Research Observer,* 14: 277–293.

Mengistu, U. 2007. Performance of the Ethiopian Somali goats during different watering regimes. PhD Thesis, Uppsala: Sveriges lantbruksuniv.,*Acta Universitatis agriculturae Sueciae*, 7.

Mesfin, A. and Jutzi, S. 1993. The joint project on vertisols management. Retrospect and prospect. In: Takalign, M., Abiye, A., Srivastya, K.L., Asgelil, D. (Eds). Improved management of vertisols for sustainable crop-livestock production in the Ethiopian highlands: Synthesis report 1986-92. Technical committee of the joint vertisol project, Addis Ababa, Ethiopia. pp. 147-157.

Meze-Hausken, E. 2004. Contrasting climate variability with perceived climate change response of a catchment to climate and land use changes in Tropical Africa: case study South Central Ethiopia. *Journal of Hydrology*, 275: 67–85.

Meze-Hausken, E. 2000. Migration caused by climate change: how vulnerable are people in dry land areas? Mitigation and Adaption Strategies for Global Change, 5: 379–406

Ministry of Agriculture. 2000. Agro-Ecological Zones of Ethiopia, MOA, Addis Ababa, Ethiopia.

Ministry of Finance and Economic Development. 2011. GTP annual progress report 2010/11. www.mofed.gov.et. Viewed on 17 March 2013.

Ministry of Finance and Economic Development. 2008. Report on Dynamics of Growth and Poverty in Ethiopia (1995/96-2004/05), Addis Ababa, Ethiopia

Ministry of Finance and Economic Development. 2006. Ethiopia: Building on Progress: A Plan for Accelerated and Sustained Development to End Poverty, (2005/06-2009/10), Volume I: Main Text, MoFED, September, 2006, Addis Ababa.

Mogo, F.C. 2002. Assessment of Heavy Metals in Soil, Water, Sediments and Certain Plant Taxa in Imo and New Calabar Rivers. Ph.D Thesis, University of Port Harcourt, Port Harcourt, Nigeria.

Mohamed-Saleem, M.A. 1985. The establishment and management of fodder banks In: Van Kaufmann, Chater, S. and Blench, R. (Eds.). In: *Proceedings of the ILCA/NAPRI Symposium on Livestock Production,* Nigerian Sub Humid Zone Kaduna, Nigeria, 29 October- 2 November, 1984. ILCA, Addis Ababa, Ethiopia. pp. 326-350.

Moss, A.R., Jouany, J.P. and Newbold, J. 2000. Methane production by ruminants: Its contribution to global warming. *Annals of Zootechnology*, 49: 231-253.

Ministry of Water Resources. 2002. Water sector development programme 2002- 2016, Volume II: Main Report. MoWR, Federal Democratic Republic of Ethiopia, Addis Ababa, Ethiopia.

Ministry of Water Resources. 2001. Initial National Communication of Ethiopia to the United Nations Framework Convention on Climate. National Meteorological Service Agency, Addis Ababa Ethiopia.

Murwira, H.K., Swift, M.J. and Frost, P.G.H. 1995. Manure as a key resource in sustainable agriculture. In: Powell, J.M., T.O. Fernandez-Rivera, T.O. Williams and C. Renard. (Eds.). Livestock and Sustainable Nutrient Cycling in Mixed Farming Systems of sub-Saharan Africa. In. *Proceeding of International Conference,* 22-26 November 1993. International Livestock Center for Africa (ILCA), Addis Ababa, Ethiopia. pp. 131-149.

Mwendera, E.J. and Mohamed-Saleem, M.A. 1997. Hydrologic response to cattle grazing in the Ethiopian highlands. *Agriculture, Ecosystems and Environment*, 64 (1): 33-41.

Naqvi, S.M.K. and Sejian, V. 2011. Global Climate Change: Role of Livestock. *Asian Journal of Agricultural Sciences*, 3 (1): 19-25.

Nigatu, A., Getachew, G., Drucker, A. 2004. Reasons for the Loss of Animal Genetic Resources and the Importance of IK in Animal Genetic Resources Management. *Proceedings of the 11th annual conference of the Ethiopian Society of Animal Production* held in Addis Ababa, Ethiopia, August 28-30, 2003. pp. 37-46.

National Meteorological Service Agency. 2007. Climate Change National Adaptation Program of Action (NAPA) of Ethiopia, NMSA, Addis Ababa, Ethiopia.

National Meteorological Service Agency. 2001. National Meteorological Services Agency under the GEF supported Climate Change Enabling Activities Project of Ethiopia. United Nations Educational, Scientific, and Cultural Organization. Federal Democratic Republic of Ethiopia Ministry of Water Resources National Meteorological Services Agency. Initial National Communication of Ethiopia to the United Nations Framework Convention on Climate Change, June 2001 Addis Ababa, Ethiopia.

Nordhaus, W. 2008. A Question of Balance. Yale, CT: Yale University Press. pp.209.

National Research Council. 1981. Effects of environment on nutrient requirements of domestic animals. Subcommittee on environmental stress, committee on animal nutrition, NRC, Washington, DC, National Academic Press, pp.168.

National Research Council. 2000. Nutrient Requirement beef cattle-seventh revised edition. Subcommittee on Beef Cattle Nutrition, National Research Council, Washington, DC, National Academy Press. pp. 248.

National Research Council. 2001. Nutrient Requirements of Dairy Cattle 7th review edition. National Research Council, Washington, D.C. National Academy Press.

National Research Council. 2010. Advancing the Science of Climate Change. National Research Council, the National Academies Press, Washington, DC, USA.

O'Donovan, P.B., Soomro, F.M., Wagenaar,J. P., Shafiq-ur-Rehman and Farhat A. B. 1997. Urea treatment of straw: A farmer - friendly system improved upon in Balochistan. Livestock Research for Development, Volume 9, No 5.*L*ivestock and Dairy Development Department, Government of Balochistan, Pakistan.

Olkowski, A.A. 2009. Livestock Water Quality: A Field Guide for Cattle, Horse, Poultry and Swine. Ministry of Agriculture and Agri-Food Canada, University of Sakska tchewan, Saskatoon. Canada.

Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, L.A. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U.S. Department of Agriculture Circular 939.

Pearson, T., Walker, S. and Brown, S. 2005. Sourcebook for land use, land-use change and forestry projects. Winrock International and the Bio-Carbon. *Fund of the World Bank,* pp. 57.

Peden, D., Freeman, A., Astatke, A. and Notenbaert, A. 2006. Investment Options for Integrated Water-Livestock-Crop Production in Sub-Saharan Africa. Working Paper 1. International livestock research institute, Nairobi, Kenya.

Peden, D., Tadesse, G. and Misra, A.K. 2007. Water and livestock for human development. In: D. Molden (Ed). Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture. London: Earth scan and Colombo: IWMI.

Petersen, S.O., Lind, A.M. and Sommer, S.G. 1998. Nitrogen and organic matter losses during storage of cattle and pig manure. *Journal of Agricultural Science Cambridge*,130: 69–79.

Pond, W.G., Church, D.C., Pond, K.R. and Schoknecht, P.A. 2005. Basic Animal Nutrition and Feeding (5th Ed). John Wiley and Sons, Inc. USA.

Post, W.M. and Kwon, K.C., 2000. Soil Carbon sequestration and land-use change, Processes and potential, *Global Change Biology*, 6: 317-328.

Powell, J.M., FernaÂndez-Rivera, S., Williams, T.O. and Renard, C. 1993. Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa. Vol II: Technical papers, (Eds J. M. Powell, S. FernaÂndez- Rivera, T. O. Williams, and C. Renard), In: *Proceedings of an international conference* held in Addis Ababa, Ethiopia, 22 to 26 November 1993*,* Addis Ababa: International Livestock Centre for Africa.

Reeder, J.D. and Schuman, G.E. 2002. Influence of livestock grazing on carbon sequestration in semi-arid mixed-grass and short-grass rangelands. *Envronmental Polution*, 116: 457 - 463.

Reilly, J., Jacoby, H. and Prinn, R. 2003. Multi-gas Contributors to Global Climate Change: Climate Impacts and Mitigation Costs of non-CO_2 Gases. Pew Center on Global Climate Change, Washington, USA.

Renault, D. and Wallender, W. W. 2000. Nutritional Water Productivity and Diets: From Crop per drop towards Nutrition per drop. Agricultural Water Management, 45: 275-296.

Robinson, R., Learmonth, A., Hutson, M., Macleod, C., Sparks, T., Leech, D., Pierce, G., Rehfisch, M. and Crick, H. 2005. Department for Environmental, Food and Rural Affairs. “Climate Impact on Migratory birds, in Climate change and Migratory species Change and Migratory. Defra Publications, London.

Rodriguez, J.A., Nanos, N., Grau, J.M., Gil, L. and Lopez-Arias, M. 2008. Multi-scale analysis of heavy metal contents in Spanish agricultural top soils. *Chemosphere,* 70:1085–1096.

Rosegrant, M.W., Cai, X. and Cline, S.A. 2002. Global Water Outlook to 2025, Averting an impending Crisis. A 2020 vision for food, agriculture and the environment initiative. International Food Policy Research Institute and International Water Management Institute.

Rosenberg, N.J., Izaurralde, R.C. and Malone, E.L. 1999.Carbon sequestration in soils: science, monitoring and beyond. In Proceedings of St. Michaels Workshop*,* Columbus, OH, December 1998 Battelle Press; Boca Raton, USA, CRC Press.

Rotz, C.A., 2004. Management to reduce nitrogen losses in animal production. *Journal of Animal Science*, 82 (E.Suppl.): E119-E137.

Schneiders, F. 2006. Livestock and the Environment.InfoAgrar News, Zollikofen, InfoAgrar PP 6-8. *Science*, 204: 1623-1627.

Sejian, V., Lal, R., Lakritz, J. and Ezeji, T. 2010. Measurement and prediction of enteric methane emission. *International Journal of Biomateorology*, DOI: 10.1007/s00484-010-0356-7.

Sisay, M. 2007. Assessment of the Ecological Impacts of Floriculture Industries Using a Physico-chemical parameters and Benthic Macroinvertebrate Meteric Index along Wedecha River, Debrezeit Ethiopia. M.Sc. Thesis. Addis Ababa University. School of Graduate Studies Environmental Science. Addis Ababa, Ethiopia.

Smith, S.R. 2008. A critical review of the bioavailability and impacts of heavy metals in municipal solid waste composts compared to sewage sludge. *Environment International*, EI-01795: 15.

Soares dos, S.F., Sobrinho, M.N., Nelson, M. and Clarice de. O. 2003. Heavy Metals contamination in Soil and plant by intensive use of pesticides and fertilizer. Universidade Federal Rural do Rio de Janeiro. BR 465, km 7. CEP 23890-000.Serope dica, Rio de Janiero, Brazil.

Solomon, A. 2006. Assessing the biological integrity of the great Akaki River using Macroinvertebartes. M.Sc Thesis. Addis Ababa University. School of Graduate Studies. *Environmental Science*. Addis Ababa, Ethiopia.

Solomon, D. 2000. Pastoralism and Natural Resources Management: the case of pastoral Borana in southern Ethiopia, *Proceedings of the 8th annual conference of the Ethiopian Society of Animal Production* held in Addis Ababa, Ethiopia, August, 2000.

Soon, Y.K., Arshad, M.A., Haq, A. and Lupwayi, N. 2006. The influence of 12 year of tillage and crop rotation on total and labile organic carbon in a sandy loam soil. Soil and Tillage research, 95 (1-2): 38-46. Statistical Package for Social Sciences. 2008. SPSS version 17.0.1 for windows. SPSS Inc., U.S.A.

Srivastava, K.L., Abiye, A., Tekalign, M., Hailu, R. and Selamyihun, K. 1993. Land, soil and water management In: Takalign, M., Abiye, A., Srivastya, K.L., Asgelil, D. (Eds). Improved management of vertisols for sustainable crop-livestock production in the Ethiopian highlands: Synthesis report 1986-92. Technical committee of the joint vertisol project, Addis Ababa, Ethiopia. pp. 75-84.

Stallknecht, G. F. 1997. New Crop Fact Sheet "Teff", Purdue University, Centre for New Crops and Plant Products. http://www.hort.purdue.edu/newcrop/cropfactsheets/teff.html#Scientific%20Names Accessed January, 2011.

Steinfeld, H., de Hann, C. and Blackburn, H. 1998. Livestock-environment interaction: issues and options. Report of a study by WREN media, Fressingfield, EYE, Suffolk, IP21 5SA, United Kingdom.

Steinfeld, H., Geber,P., Wassenaar, T., Castel, V., Rosales, M. and de Haan, C. 2006. Livestock's long shadow: Environmental issues and options. Livestock Environmental and Development, FAO, Rome Italy.

Stern, N. 2007. The Economics of Climate Change: The Stern Review. Cambridge University Press: Cambridge and New York.

Sundermeier, A., Reeder, R. and Lal, R. 2005.Soil Carbon Sequestration—Fundamentals, Extension Fact Sheet AEX–510–05, The Ohio State University Extension, Columbus, Ohio.

Sutherst, R.W., Yonow, T., Chakraborty, S., O'Donnell, C. and White, N. 1996. A generic approach to defining impacts of climate change on pests, weeds and diseases in Australasia. In: Greenhouse: Coping with Climate Change [Bouma, W.J., G.I. Pearman, and M.R. Manning (Eds.)]. CSIRO Publishing, Collingwood, Victoria, Australia, pp. 281-307.

Tadesse, G. and Peden, D. 2003. Livestock grazing impact on vegetation, soil and hydrology in a tropical highland water shed. In: McCornick, P.G., Kamara A.B. and Tadesse G. (eds), Integrated water and land management research and capacity building priorities for Ethiopia, *Proceedings of a MoWR/EARO/IMWI/ILRI international workshop* held at ILRI, Addis Ababa, Ethiopia, 2–4 December 2002. International Water Management Institute, Colombia, Sri Lanka, International Livestock Research Institute, Nairobi, Kenya, Ethiopian Agricultural Research Organization, Addis Ababa, Ethiopia, and MoWR, Addis Ababa, Ethiopia. pp. 87-97.

Tadesse, T., Haque, T. and Aduayi, E.A. 1991. Soil, plant, water, fertilizer, animal manure and compost analysis manual, ILCA PSD Working Document, B13. International Livestock Center for Africa, Addis Ababa, Ethiopia.

Tamiru, A., 2006. Heavy metal concentration in the urban Environment of Addis Ababa, Ethiopia. *Soil and sediment contamination*, 15: 1-12.

Tamiru, A., 2001. The impact of uncontrolled waste disposal on surface water quality in Addis Ababa. *Ethiopian Journal of Science,* 24 (1): 93-104.

Tamiru, A., Dagnachew, L., Tenalem, A., Yirga, T., Solomon,W. and Nuri, M. 2005. Hydrogeology, water quality and the degree of ground water vulnerability to pollution in Addis Ababa, Ethiopia. UNEP and UNESCO. Addis Ababa, Ethiopia. 111pp.

Tamiru, A., Solomon, W. and Yirga, T. 2003. Surface and ground water pollution status in Addis Ababa, Ethiopia http//:www.un.urbanwater.net/cities/addababa.html

Tareke, B. 2010. Increasing Productivity of Teff: New Approaches with dramatic results. Sasakawa Africa Association, Regional Office, Addis Ababa, Ethiopia. Report.

Tekalign, M. and Haque, I. 1987. Phosphorus status of some Ethiopian soils. I. Sorption Characteristics. *Plant and Soil,* 102: 261-266.

Tekalign, M., Haque, I. and Kamar, C.S. 1988. Phosphorus status of some Ethiopian soils. In Jutzi S.C, Haque I, McIntire J. and Stares, J. E. S. (Eds) 1988. Management of vertisols in sub-Saharan Africa, Proceedings of a conference held at ILCA, Addis Ababa, Ethiopia. 31 August-4 September 1987. ILCA, Addis Ababa.

Tesfaye, K., Madsen, J.O. and Azage, T. 2004. Manure Production, Handling and Use Around Holetta Agricultural Research Center. The Role of Agricultural Universities/Colleges in Transforming Animal Agriculture in Education, Research and Development in Ethiopia: Challenges and Opportunities. In *Proceedings of the 13th Annual conference of the Ethiopian Society of Animal Production* held in Addis Ababa, Ethiopia, August 25-27, 2004. pp. 3-12.

Tesfaye, S. 2007. Assessment of Ground Water and Its Vulnerability to Pollution by Vertical Electrical Sounding in Ada Plain. M.Sc. Thesis. Addis Ababa University. School of Graduate Studies. *Environmental Science*. Addis Ababa, Ethiopia 96 pp.

Tezera, G., Nura,D., Hirsi, A. and Mohammedsurur, A. 2010. Camel keepers in Ethiopia at a glance. Pastoralist forum Ethiopia, Endogenous Livestock Development FAO International Technical Conference on Animal Genetic Resources. Interlaken, Switzerland, pp.1-9.

Tibebu, S. 2007. Water Interaction and Water Productivity of Dairy Cattle in Wuchale Wereda, Nile River Basin, Ethiopia. M.Sc. Thesis. Addis Ababa University. School of Graduate Studies Environmental Science. Addis Ababa, Ethiopia.86pp.

Tittonell, P., Rufino, M.C., Janssen, B.H. and Giller, K.E. 2010. Carbon and nutrient losses during manure storage under traditional and improved practices in smallholder crop-livestock systems—evidence from Kenya, Plant and Soil, 328 (1-2):253-269.

Turnbull, G. and Charme, B.D. 2001. Methane Emissions-Reductions from Ruminants, Market View, Annual Spring Meeting, Phoenix, Arizona.

U.S. Environmental Protection Agency. 2006. Global Anthropogenic Non-Co_2 Greenhouse Gas Emissions: 1990-2020.

U.S. Food and Drug Administration. n.d. Guidance for Industry: Action levels for poisonous or deleterious substances in human food and animal feed. Available at: www.fda.gov/Food/GuidanceComplianceRegulatoryInformation/GuidanceDocuments ChemicalContaminantsandPesticides/ucm077969.htm. Accessed December 6, 2010.

United Nations, Scientific and Cultural Organization. 2004. World water assessment program. National water development report for Ethiopia (Final). MoWR, UNESCO and Generation Integrated Rural Development Consultant, Addis Ababa, Ethiopia.

United Nations Framework Convention on Climate Change. 1997. Kyoto Protocol. Web: http://unfccc.int

United Nations Framework Convention on Climate Change. 2013. FCCC Doha Meeting. Web: http://unfccc.int

United Nations, Office of Coordination Humanitarian Affairs. 2011. OCHA Annual Report 2011.www.unocha.org.

United States Environmental Protection Authority. 1994. International anthropogenic methane emission. Washington, DC, EPA-23-R-93-010.

Wakena, T. 2006. Operational analysis of the cascaded Wadecha-Belbela reservoir system (Ada Liben Woreda, in Oromia Region). M.Sc in hydrology and water resource management. Arbaminch University, Arbaminch, Ethiopia.

Walkley, A. and Black, I. A. 1934. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science,* 37: 29-38.

West, J.J., Arlene, M. F., Larry, W. H. & Denise, L. M. 2006. Global Health Benefits of Mitigating Ozone Pollution With Methane Emission Controls. *Proceedings of the National Academy of Sciences.* March 14, 2006, 103 (11): 3988-3993.

World Food Program. 2003. Emergency report 2002/3. Available at: http://www.wfp.org/index.asp?section=2 Accessed 28 April 2004.

Whalen, J.K. and Chang, C. 2002. Macro-aggregate characteristics in cultivated soils after 25 annual manure applications. *Soil Science Society of America Journal*, 66: 1637 - 1647.

White, E.M., Krueger, C.R. and Lugo, A.E. 1987. Changes in total N, organic matter, available P, and bulk densities of cultivated soils 8 years after tame pastures were established. *Agronomy Journal,* 68: 581-583.

White, J.W., Taneer, D.G. and Corbett, J.D. 2001. An agro-climatological characterization of bread wheat production areas in Ethiopia. NRG-GIS Series 01-01. Mexico, D.F., CIMMYT.

World Health Organization. 2009. Department of health statistics and health information systems, World Health Statistics.

World Health Organization. 2004. World Health Report 2004 – Changing History. WHO, Geneva, Annex Table 2, pp.120.

Wikipedia. 2011. List of countries by greenhouse gas emission. en.wikipedia.org/.../List_of_countries_by_greenhouse_gas_emissions. Viewed 6 April 2013.

Wilbanks, T.J., Lankoa, P.R., Bao, M., Berkhout, F., Cairncross, S., Ceros, J.P., Kapshe, M., Muir-Wood, R. and Zapata-Marti, R. 2007. Industry settlement and society. In: M.L Parry, O.F. Canziani, J.P. Palutikof, p.J. van der Linden and C.E. Hanson (Eds). Impacts, adaptation and vulnerability. Contribution of working group 2 to the 4th assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, United Kingdom.

Wilhite, D.A. 2000. Drought: a global assessment. Routledge, London.

Wilhite, D.A. and Glantz, M.H. 1985. Understanding the drought phenomenon: the role of definitions. *Water International,* 10:111–120.

Williams, D.E., Vlamis, J., Pukite, A.H. and Corey, J.E. 1980. Trace element accumulation, movement and distribution in the soil profile from massive applications of sewage sludge. Soil Science 129, 119-132.

Williams, T.O., Powell, J.M. and Fernandez-Rivera, S. 1995. Manure utilization, drought cycles and herd dynamics in the Sahel: implications for cropland productivity. In: J. M. Powell, S. FernaÂndez-Rivera, T. O. Williams, and C. Renard (eds). Livestock and sustainable nutrient cycling in mixed farming systems of sub-Saharan Africa. Vol II: Technical papers*. Proceedings of an international conference* held in Addis Ababa, Ethiopia, 22 - 26 November 1993. ILCA, Addis Ababa.

World Overview of Conservation Approaches and Technology Categorization System .n.d. https://www.wocat.net/fileadmin/user_upload/documents/ Viewed 8 March 2013.

Wondimu, A. and Tekabe, F. 2001. Utilization of Teff in the Ethiopian diet. In: Narrowing the Rift. Teff research and development. In: H.Tefera, G.Belay and M. Sorrells (Eds). *Proceedings of the International Workshop on Teff genetics and improvement,* 16-19 October 2000, Debrezeit, Ethiopia, pp. 239-244.

Wood, C.W., Edwards, J.H. 1992. Agro-ecosystem management effects on soil carbon and nitrogen. *Agriculture, Ecosystems and Environment*, 39 (3-4): 123-138.

World Bank. 2011. World development indicators 2011.

World Bank. 2010. Cities and climate change: An urgent agenda. The international bank for reconstruction and development. *The World Bank*, Washington, DC.

World Bank. 2003. Ethiopia: Risk and Vulnerability Assessment, Draft Report Washington D.C.

World Resources Institute. 2012. CAIT version 9.0. Washington, DC: World Resources Institute. Available online at: http://cait.wri.org. Viewed on 16 April 2013.

World Resources Institute. 2007. Earth trends: Environmental Information. Available at http://earthtrends.wri.org. Accessed Jan, 2011.

Yimer, A. 1992. Nitrogen transformation in some Ethiopian highland vertisols. PhD thesis, University College of Wales, Aberystwth, UK.

Yesuf, M., Di Falco, S., Ringler, C. and Kohlin, G. 2008. Impact of climate change and adaptation to climate change on food production in low income countries: Household survey data evidence from the Nile basin of Ethiopia. Discussion Paper No. 828. International Food Policy Research Institute, Washington, D.C.

Yoseph, M., Azage, T., Alemu, Y. and Ummuna, N.N. 2002. Evaluation of the general farm characterization and dairy herd structure in urban and peri-urban dairy production systems in the Addis Ababa milk shed. Proceedings of the 10th Annual Conference of the Ethiopian Society of Animal Production (ESAP), August 2002, Addis Ababa, Ethiopia, pp. 137-144.

Yoseph, M., Azage, T., Alemu, Y. and Umunna, N.N. 1999. Nutritional management of dairy herds in urban and peri-urban dairy production systems. Proceedings of the International Conference on the Nutrition of Herbivores, April, 1999, Texas, USA.

Zarcinas, B.A., Ishak, C.F., McLaughlin, M.J. and Cozens, G. 2004. Heavy metals in soils and crops in Southeast Asia. 1. Peninsular Malaysia. *Environment and Geochemical Health,* 26: 343–357.

Zenebe, G., Meseret, M. K. and Alemu M. 2011. Crop-livestock inter-linkages and climate change implications on Ethiopia’s Agriculture: a Ricardian Approach. In: Climate change workshop, 20 July 2011 organized by EEPFE and EDRI, Addis Ababa, Ethiopia.

Zhang, H., Hamilton, D.W. and Britton, J. G. 2001. Sampling animal manure. Oklahoma, University press, USA. 70pp. http://www.soiltesting.okstate.edu/Extn_Pub/F-2248web.pdf.

Zinash, S., Azage, T. and Getnet, T. 2003. Water resources for livestock in Ethiopia: Implications for research and development. In: P.G McCormick, A.B. Kamara and G. Tadesse (eds), Integrated water and land management research and capacity building priorities for Ethiopia, Proceedings of a MoWR/EARO/IMWI/ILRI international workshop held at ILRI, Addis Ababa, Ethiopia, 2–4 December 2002. IWMI, Colombia, Sri Lanka, ILRI, Nairobi, Kenya, EARO, Addis Ababa, Ethiopia, and MoWR, Addis Ababa, Ethiopia. pp. 66-79.