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Rainfall variability, soils and land use changes in the highlands of Ethiopia

Staffan Rosell

UNIVERSITY OF GOTHENBURG

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Abstract

Most farmers in the Ethiopian highlands are dependent on rain-fed agriculture. The indigenous cereal tef is the most important crop for the farmers in the highlands. The central highland is an environmentally fragile area and a marginal area of Ethiopia with a recurring problem for the farmers to sustain an adequate agricultural production.

The objectives of this thesis are; to analyse the rainfall change and rainfall variability in time and space and its impact on farmers' potential to cultivate during the short rainy season *Belg*; to analyse the status of soil parameters and its consequences for farmers' food production and; to analyse land-use changes and its consequences for the farmers dependent on agriculture. The geographical focus is on the central highlands and especially South Wollo. The rainfall analysis is based on daily rainfall data from 13 stations and covers the time period 1964-2012. Land use and land cover changes were analysed by interpretation of black and white aerial photographs from 1958 and colour satellite images from 2003 and 2013. All soil samples used in the study were analysed according to standard methods. In addition interviews with farmers and field observations were done during six different field campaigns between 1999 and 2012.

The results reveal a decline in the total *Belg* rainfall since the 1980´s in the central highlands. The total amounts of rainfall during the long rainy season, called *Kiremt*, have increased during the same time period. An increase in the rainfall variability over time is also found. The increased rainfall variability is also found when comparing two adjacent places only 30 km apart. It is also found that the synchronicity of rainfall between the two adjacent stations is very low during *Belg*, but higher during *Kiremt* season. A rainfall model for tef cultivation is developed and used as a tool to analyse the impact of rainfall changes on tef cultivation. The model suggests that during the time period 1963-1982 and 1984-2003 farmers were able to have a potential tef harvest every second year during both these twenty-year periods. The model also shows that the possibilities to grow tef at Combolcha after 1996 has become more difficult and the possibilities to grow tef during the *Belg* season are very limited today.

A comparison of the soils´ nutrient status and mechanical properties in Tehuledere and Wenchi shows that most parameters are found within a normal range however, the organic matter content is very low in Tehuledere, which may explain a lower soil productivity compared to Wenchi. This also confirms the farmers' perception regarding the soil productivity in Tehuledere. The study also suggests that different cropping strategies such as enset plantation may have a significant positive effect on the soil status.

An increase in the number of houses and a decrease of farm land during the past 50 years suggest that land is more intensively used today. The fact that the farmers claimed that they not have been able to have land in fallow may confirm this. New techniques such as water harvesting ponds introduced in the study area in 2009, as well as the development of irrigation systems along a creek introduced in 1999, are measures that may increase the agricultural production and enable some farmers to develop and improve their farming strategies.

The findings presented in this thesis shows that there is a need to improve the soil productivity parameters such as organic matter in many areas. The change in rainfall shows that the impact rainfall has on farmers potential to grow tef varies from one place to another. Some farmers having access to larger land, access to irrigation or water harvesting have improved their livelihood situation, but on the other hand some farmers have ended up in a more difficult situation due to changes of rainfall, sometimes in combination with problems with soil productivity. Future studies of the farmers' situation such as analysis of land-use changes, analysis of farming strategies and adaptation due to the rainfall changes are important to understand how to reduce poverty in rural Ethiopia in the future.

Keywords: rainfall change, soil productivity, tef, land-use changes, water harvesting, South Wollo

Preface

l. Regional perspective on rainfall change and variability in the central highlands of Ethiopia, 1978-2007

II. An analysis of soil productivity parameters and Livelihoods in West Shewa and South Wollo, Ethiopia

III. Rainfall change and its implications for *Belg* harvest in South Wollo, Ethiopia

IV. Erratic rainfall and its consequences for cultivation in two adjacent areas in South Wollo

V. Land use changes in a small catchment, South Wollo, Ethiopia. Trends and impacts on rural households´ farming

The thesis consists of five papers. I am the lead author in all five of them. Paper I is written by me alone. Paper II is based on fieldwork performed by me and Mats Olvmo after a reconnaissance trip I had done a year earlier. The analyses and writing process were done jointly by Dr Mats Olvmo and me at the Department of Earth Sciences. In paper III Dr Björn Holmer was instrumental in the creation of the rainfall model as a vital part of the analysis. We worked jointly on this model based on discussions with farmers and the rainfall data. The fourth paper focus on climate change and once again Dr Björn Holmer and me worked together and discussed the paper from the very start. Paper V was based on the fieldwork I conducted during several weeks in Tehuledere in South Wollo. The maps were produced by Dr Mats Olvmo and Dr Björn Holmer did most of the writing process, but all three authors were involved in the writing process.

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Part 2 - Papers I-V

Prologue

There is a narrow gravel road between the small town of Hayk and the village of Kete in the Ethiopian highlands. Once you are getting closer to Kete, housing areas are getting fewer and when the tree line-road ends right below the orphanage, where the small river bends west, the landscape opens up. Intense cultivation on the valley floor and the mountain ridge as a backdrop makes the area a beautiful place to live. In Kete, small areas of houses, usually in clusters on slightly higher ground than the nearby fields, are common. Small pathways lead you between the houses. Eucalyptus trees give a well needed shade for farmers and animals. A life mostly based on what the land could produce in terms of food for the household and hopefully a bit of surplus to sell at the market in Hayk town is the reality for most people living here. For some, the food aid delivery is also part of the life in Kete. In May 1941, the emperor Haile Selassie returned from exile after a few turbulent years in Ethiopia and the Italian occupation in parts of the country was over (Marcus 2002). The same year, a child was born in Kete in South Wollo in the Amhara region. The boy has lived in Kete since his birth. He is now over 70 years old. In the late 1950´s, he established himself as a farmer in Kete. He had learnt his trade from his parents, and land was divided so he was able to grow his crops. His two years younger brother also settled on the farm land that belonged to their parents, and just like his brother he lives in the village. Their parents had 1 hectare of land, which means that the two brothers have 0.5 ha each to cultivate today. The brothers have experienced a lot from the perspective of being farmers in Kete during the past 50 years, including the drought in 1984 known worldwide (BBC.co.uk, 2013).

When spending time in the rural areas the nuances of poverty are experienced. Some houses are bigger and have tin roofs and some houses are smaller with grass roofs. Some farmers have larger pieces of land and some have smaller areas for cultivation. During one interview sitting on a slope adjacent to a tef field, a farmer told me about selling his house for about 100 Ethiopian Birr. Looking around, there was no house visible. I asked him: where is the house? He told me that he demounted it piece by piece and sold it as firewood. He walked six times back and forth to the market with the pieces of his home. During all my meetings with the farmers, the hardship farmers go through was perceived.

1. Introduction

Most farmers in the Ethiopian highlands are dependent on rain-fed agriculture. Around 83% of the Ethiopian population live in rural areas and rely on what the land can produce for their income and daily food in-take. The central highland is a region known for having problems with food security (Tschopp et al. 2010; Haile et al. 2005; Degefu 1987; Meze-Hausken 2004; DRMFSS 2013; Bewket 2009; Viste et al. 2012; Omiti et al. 1999)

Natural conditions such as rainfall, soils, access to land and households´ access to an ox for ploughing are very important assets for a sustainable agriculture. Environmental change, for example, soil erosion is mostly affecting the cultivated areas even though farm land only makes up 13% of the total land area is a threat to farmers dependent on rain-fed agriculture (Nyssen et al. 2004). The rapid population growth that has taken place in Ethiopia since the mid-20th century and the fact that the total population was 87 million in 2013 (UN.org 2013) the problems such as soil erosion are seriously threatening crop production.

Rainfall is very important for Ethiopian farmers growing cereals preferably tef (*Eragrostis tef*), but also enset (*Ensete ventricosum*) and Sorghum (*Sorghum bicolor*) among others. Three seasons, the *Belg* season the short rainy season between February and May, the *Kiremt* season the long rainy season between July and October and the *Bega season* the driest period between November and January defines the farmers cropping seasons. The *Belg* season is short and less reliable compared to the *Kiremt* season, but it gives the farmers an option to have a second harvest of tef. The central and eastern highlands of Ethiopia are the areas that receives *Belg* rainfall, but variability is high (Meze-Hausken 2004).

After 1996, a decline in total rainfall during the short rainy season has been identified in the central highlands of Ethiopia (Bewket 2009; Viste et al. 2012). Other studies indicate an increase in rainfall variability and stresses that rainfall is essential for the farmers' possibility to grow crops (Abebe 2006; Seleshi and Camberlin 2005). In South Wollo the area used for cropping during the *Belg* season varies between 12 and 30 % of the area used for cultivation during the long rainy season (Atlas of Rural Ethiopian Economy 2006).

Famine Early Warning Systems reports a later start of the short rainy season (*Belg* season) which is causing a problematic situation for the farmers to sustain a livelihood and have a secure food situation (FEWS 2013).

In addition to changes in rainfall the soil nutrient status is of importance for farmers' agricultural production. Parameters affecting the soil conditions are type of soil, inputs such as fertilisers or manure, time since field in fallow and soil erosion (Hurni 1996; Ovuka 2000; Rosell and Olvmo 2014; Smithson 2008; Stocking 1984). Alemu and Bayu (2005) stated that low soil fertility is the biggest challenge for the farmers in the dry parts of northern Ethiopia. Soil fertility which affects the productivity of the soils is most important in all parts of rural Ethiopia.

The increased rural population in Ethiopia is a driving force behind the land use changes that has taken place in Ethiopia (Nyssen et al. 2004). The land use changes and the impact it has on farming is important when analysing the problems farmers are facing to cope with rain-fed agriculture. Several studies such as: (Amsalu et al. 2007; Bewket and Abebe 2013a; Getachew and Melesse 2012; Tegene 2002) show that the pressure on turning marginal tree covered and shrub-land into cultivation is common in Ethiopia. When analyzing the changes more specific in South Wollo earlier studies show that the percentage cultivated land has not changed significantly during the past decades but population has increased (Amsalu et al. 2007; Asmamaw et al. 2011; Tegene 2002; Tekle and Hedlund 2000).

A household's different asset can be grouped into different categories such as the natural, physical, human, social and financial assets (Carney 1998; Scoones 1998). This thesis is focusing on the natural assets rainfall, soils and access to land. Other physical, human and social assets such as access to ox, labour involved in the agriculture activity in farming groups are only partly covered in the thesis.

The changes in rainfall, the status of the soil parameters and the land use changes that has taken place are essential, however gaps in knowledge still exists when it comes to the understanding and the impact these factors have on farmers daily life who are dependent on agriculture. More research dealing with changes in rainfall, analysis of soil status as well as land use and land cover changes in an area known to be vulnerable to have a secure food production is important (DRMFSS 2013).

Those issues may hopefully help to increase the understanding the rural population in the Ethiopian highlands are struggling with.

It may also lead to recommendations such as adaptation of type of crops, diversification of the cropping strategies, water harvesting, most favourable seeding time can hopefully improve the rural livelihoods situation for farmers to be able to produce a surplus and end up in a better situation when dependent on agriculture.

2. Purpose of this thesis

The objectives of this thesis are to analyse the rainfall change and rainfall variability in time and space and its impact on farmers' potential to cultivate during the short rainy season; and to analyse the status of soil parameters and its consequences for farmers' food production and to analyse land-use changes and the consequences this has for the farmers dependent on agriculture.

Specific research objectives are:

-To analyse regional differences in the central highlands of Ethiopia in the variability and intensity of rainfall both annual seasonal and the start of the short and long rainy seasons during the time period 1978-2007. (Paper I)

-To analyse soil productivity parameters at two sites in South Wollo & South West Shewa in the central highlands of Ethiopia. (Paper II)

-Investigate rainfall changes and rainfall variability in the eastern part of South Wollo and its impact on tef cultivation during the short rainy season. (Paper III)

-To analyse two adjacent sites, Combolcha and Hayk in South Wollo, located only 30 km apart but with different amount of rainfall, to show how details in the rainfall distribution influence tef cultivation. (Paper IV)

-To investigate the land use and land cover changes in Kete Kebelle between 1958 and 2013 and analyse its consequences for the farmers dependent on agriculture (Paper V).

3. Geographical setting

3.1 Population

Ethiopia is the largest country on the horn of Africa, surrounded by Eritrea, Sudan, South Sudan, Kenya, Somalia, and Djibouti. Since the breakaway of Eritrea in 1993 Ethiopia is one of fourteen land-locked countries on the African continent. Ethiopia covers an area of approximately 1.1 million square km which means that Ethiopia is the tenth largest country in terms of land mass on the continent. With a population of 87 million people in Ethiopia is the second most populous country in Africa. It has a young population with 64 % aged 24 or younger. The capital of Ethiopia, Addis Ababa is by far the biggest city in the country with a population of approximately 2.9 million people in year 2009. Only 17% of the Ethiopian population lives in urban areas, which means that 83 % lives in rural areas where agriculture is the main source of income. The Amhara and Oromo speaking groups are dominating ethnic groups. Sixty percent of the Ethiopians belong to these two groups. In terms of religion the orthodox group (43 %) and the Muslims (33 %) are the dominating (CSA.gov.et 2014; CIA 2014).

In figure 1 the population density is shown. A majority of the population in Ethiopia lives in the highland areas of Ethiopia. The lowlands in the east area have a low population density.

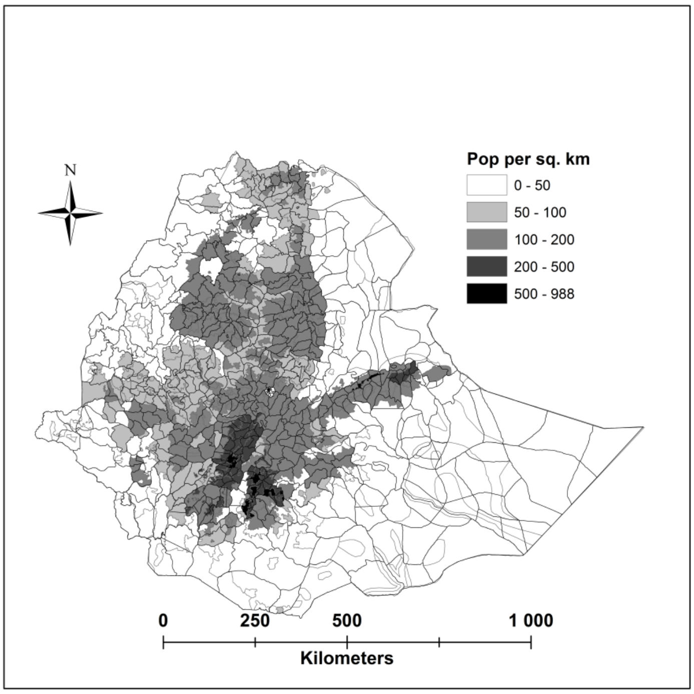


Figure 1. Population per sq. km

Source: (USAID 2009) & (EthioGIS 1999), 1999 Compiled by: Staffan Rosell

The administrative system in Ethiopia divides the country into regions such as Amhara and Oromia. The next administrative level is zones such as South Wollo and West Shewa this is followed by the next administrative level called *woredas* such as Tehuledere and Woliso. The administrative level at village level is called *kebelles* such Kete and Fite Wato and within each *kebelle* there are *Gots* or *Gotis*. Examples of *Got* or *Gotis* visited during fieldwork are Fagaro in Kete and Chorro in Fite Wato.

3.2 Topography of Ethiopia

The Ethiopian topography is considered the main reason for the rainfall pattern found in the country. From the eastern lowlands only a few hundred meters above sea-level to peaks above 4000 m.a.s.l. in the western part of the country and then lower in the most western part of Ethiopia, in the area bordering Sudan and South Sudan. This is a result of the formation of the

Great Rift Valley that goes from the north-eastern part of the country in a south-western direction (Figure 2).

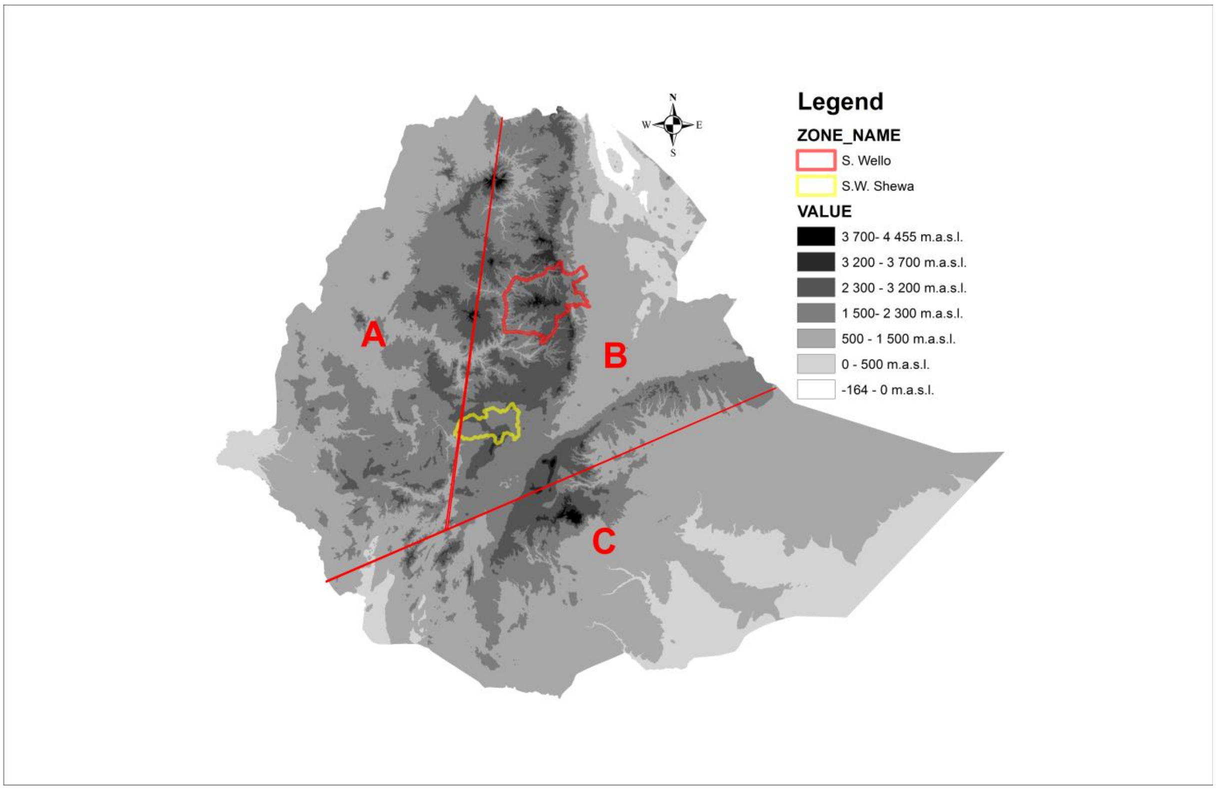


Figure 2. Topography of Ethiopia and rainfall pattern. **A**=One rainy season *Kiremt* **B**= *Belg* and *Kiremt* March-May and July-September **C**= September-November and March-May two wet seasons

Source: (NMSA 1996); (Diro et al. 2011);(EthioGIS 1999) Compiled by: Staffan Rosell

3.3 Climate

Rainfall is higher over the highlands areas compared to the low lands areas of Ethiopia. The western part of the country receives the highest amount of up to 2000 mm of rainfall on annual basis compared to the eastern lowlands that only receives around 400 mm. Ethiopia is divided into different rainfall zones. Thus while the western part has a uni-modal rainfall regime the central and southern parts of the country has a bi-modal rainfall regime. The map below shows a simplified model of the rainfall pattern of Ethiopia.

Rainfall is the backbone for agricultural production in the Ethiopian highlands but it varies significantly in amount and distribution from different regions of Ethiopia. The central highlands though are homogenous in that sense that there are three seasons, the short rainy season named *Belg*, the long rainy season named *Kiremt* and the drier season named *Bega* (Atlas of Rural Ethiopian Economy 2006; Diro et al. 2011) and Paper I). The *Belg* rainfall is caused by south-easterly winds that carry moist air from the Indian Ocean producing rainfall in February, March, April and May. This is followed by a short dry spell in the month of June before the movement of ITCZ on the African continent reaches Ethiopia which results in a low-pressure system that covers most of the country between July and September. In October or November north-easterly winds leads to drier conditions lasting until January. This is the *Bega* season. (Camberlain 1997; Conway 2000; Diro et al. 2011; Seleshi and Zanke 2004).

A complex situation emerges when looking at studies on rainfall changes in Ethiopia during the last century. In Addis Ababa there are recordings since the early 20th century (Conway et al. 2004). This study showed little or no trend in the rainfall for the past 100 years. The data indicates that dry years in Addis Ababa do not correspond with dry years elsewhere in Ethiopia. The Addis Ababa data is the only long time series of climate found in Ethiopia, however several stations were established in the 1950´s. Conway (2000) found no clear trend in rainfall in South Wollo in that study but studies focused on rainfall during recent time period like (Bewket 2009) has found a decline in *Belg* rainfall from the mid 1990´s. On the other hand (Meze-Hausken 2004) did not find any decline in rainfall over the north and north-eastern parts of the country. (Conway et al. 2004) found a small increase during the last century based on the minimum and maximum temperature data set from the Addis Ababa station. They also found that it is the minimum temperatures that has had the largest increased when comparing the minimum and maximum data series.

3.4 Soils and soil productivity in Ethiopia

The geographical distribution of soil types is affecting the growing conditions. There are differences of these conditions within Ethiopia at local and regional scale. Leptosols covers about one third of the total land area of Ethiopia and are dominant in the central highlands. Leptosols are mostly found in the north and central highlands. They have a weak developed soil profile and the agricultural potential is limited. Soils considered having a good agricultural potential are Luvisols (8%) and Nitosols (12%) which are mostly found in the western and central highlands. The black clays soils Vertisols covers 10% of Ethiopia and are most common in the central highlands. Vertisols are considered having a good agricultural potential. Cambisols are brown soils covering 10% of Ethiopia. They are poorly developed soils which are mostly found in humid and semi-humid areas in the central and northern highlands of Ethiopia. Cambisols are common on slopes and stones are usually visible at surface, which makes their agricultural value low. In the dry eastern part of Ethiopia, Aridisols are the dominant soil types. They have no or little agriculture value and are used mostly for pastoralism (Atlas of Rural Ethiopian Economy 2006). Vertisols and Cambisols dominate in the study areas in South Wollo and South West Shewa are common soil types in the Ethiopian highlands (Atlas of Rural Ethiopian Economy 2006; Critchley and Gowing 2012; Gebregziabher et al. 2006).

Soil fertility is an important issue for a majority of the Ethiopian rural population. Soil fertility is the ability of a soil to support a desired level of yield and the quality of crops (Smithson 2008). Soil fertility affects soil productivity which is among several other factors a major component that determines the sustainability of smallholder farming systems in Ethiopia. Soil productivity is generally defined as the productive potential of a soil system to allow accumulation of energy in form of vegetation and comprises many factors, including individual soil parameters, climate, land management and slope. Soil nutrient status is often used as an indicator of soil productivity (Hurni 1996; Ovuka 2000; Stocking 1984).

3.5 Soil erosion and soil and water conservation

Sheet and rill erosion are common throughout Ethiopia (Nyssen et al. 2004). Gullying is most common the highland area and wind erosion in the dry lowlands. The main causes is found in the human activities and the land use changes that has taken place when vegetation has been removed and human activity such as farming has increased. There are signs of a slow-down of this due to hillside enclosures especially in northern Ethiopia. Soil and conservation methods are needed to reduce the erosion processes are urgent and needed to prevent further environmental degradation (Nyssen et al. 2004).

Different soil and water conservation techniques (Figure 4 and 5) used around the world are: vegetative strips, earth bunds, terraces and stone-bunds (Critchley 2000). In the Ethiopian highlands terracing is widely used, just as grass stripping, soil bunds, stone bunds, controlled grazing and alley cropping (Hurni 1995). There has been a long tradition of food for work in Ethiopia and one of the work tasks to receive food has been to build soil and water conservation structures e.g. soil bunds (Humanatarian practice network 2004). Recommendations of using soil and water conservation methods are recommended to the farmers via the local agricultural offices which are found on Woreda level and through development agents on kebelle level.

Figure 3. Photo of an ard plough (*maresha)*.

The plough is made of wood except for the metal knife that inverts the soil during the ploughing (Figure 3). The *maresha* is drawn by two oxen which is a most important asset in the households in rural Ethiopia. In the Ethiopian culture women are not allowed to plough the fields using oxen, this means a woman have to rely on a man that can plough her fields. The tradition also forces women to share the harvest with the man who ploughed her fields. This means she will only have half of the harvest (Aune et al. 2001; Bevan and Pankhurst 1996).

Figure 4. Photo of stone-bund in Kete kebelle

Figure 5. Photo of terracing in the central highlands south of Debre Sina.

3.6 Land use

Land tenure has been a subject that has been discussed over the past decades. The political turmoil that the country has gone through, since the Emperor Haile Selassie's days, the communist oriented Dergue regime to the liberal market oriented years with Meles Zenawi. Land is state owned but during the past decade land certificates have been distributed which opens up for land rental opportunities for the farmers and a more secure land tenure system when the household receives a certificate for the land (Bezabih et al. 2011; Tsegaye et al. 2012; Ubink et al. 2009).

14 % of the total area of Ethiopia is arable land, which means land used for either crop or pasture and 35 % of the arable land is used for agriculture. The percentage of the arable land under irrigation is very small, around 0, 5 % (WorldBank.org 2013). Land holding size is fairly small in Ethiopia, with an average of just over 1 ha per household (Atlas of Rural Ethiopian Economy 2006; Jayne et al. 2003). The average land holding size per capita is 0, 24 ha. The lowest quartile has an average of only 0, 03 ha compared to 0, 58 ha per capita for the highest quartile. There is great pressure on land in Ethiopia due to high population increase. Several studies show an increase in land used for food production. Forest areas, shrub land and areas with steep slopes are now turned into agricultural land (Amsalu et al. 2007; Bewket and Abebe 2013b; Getachew and Melesse 2012; Tegene 2002). Population has increased from approximately 21 million in year 1958 up to around 87 million in year 2010 (ESA.UN 2013a). Growth rate has in Ethiopia between just over 1, 5 % in the mid 1970´s and today it is just over 2% on annual basis. The population growth rate peaked between 1985 and 1995 with annual growth rate over 3 %. The 2% in annual population growth rate is slightly below the average on the continent (Stock 2012).

3.7 Agro-ecological zones of Ethiopia

The agro-ecological zones which is a definition of classification based on rainfall and temperature in Ethiopia (Hurni 1995). This leads to different possibilities for cultivation and suitability for crops in the different agro-ecological zones. The zones are as follows: Areas below 500 m.a.s.l. are referred to as Berha, while areas ranging from 500-1500 m.a.s.l. are called Kolla. Further, the areas between 1500 m.a.s.l. up to 2300 m.a.s.l. are termed Weyna Dega and areas covering 2300-3200 m.a.s.l. are the Dega zone. Wurch zone is the area between 3200-3700 m.a.s.l. and all land above 3700 m.a.s.l. are named high Wurch. Within each altitudinal zone there are three categories based on degree of precipitation. Thus, areas with less than 900 mm of rainfall are referred as dry areas, those areas where rainfall ranges from 900-1400 mm are moist areas, while those receiving more than 1400 mm of rainfall are referred to as wet areas. To exemplify this system, an area such as Hayk in South Wollo which receives approximately 1200 mm of rainfall and is located at an altitude of 1900 m.a.s.l. represents the combined category “Moist Weyna Dega”.

3.8 Common crops in Ethiopia and production

Figure 6. Photo of Tef

Cereal production varies within Ethiopia. The map below is the result of such an analysis, indicating the main crops in each area, as well as showing where the most important crops are tef (Figure 6) and enset. As seen in figure 7, enset is the main crop in the southern areas while tef is the primary crop in the northern areas. However, taking non-primary crops into account it is clear that tef is widespread around the country. The growing period for tef is approximately 90 days. The enset plant is grown for a time period of 4-5 years and then harvested. As seen if figure 7 barley and wheat is also grown in the highlands.

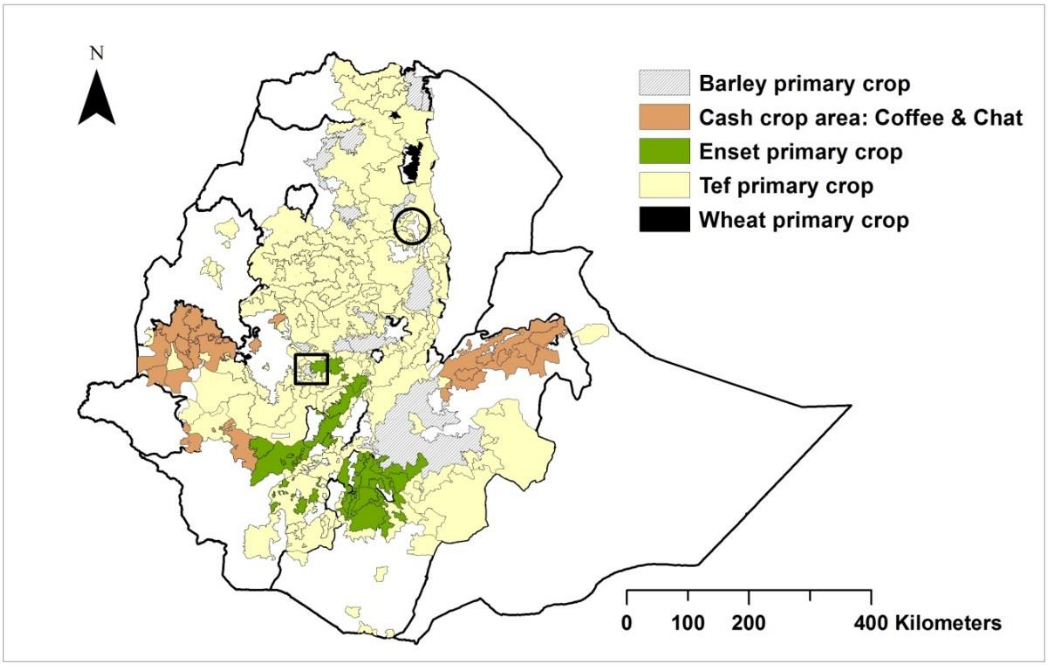


Figure 7. Most common crops in Ethiopia

○ = Tehuledere □ = Wenchi

Source: USAID Compiled by: Staffan Rosell

According to FAO statistics (FAO 2013a) the cereal yield per hectare has increased since 1989. During the time period 1991 to 2004 the harvest are averaging around 800 Kg/ha. Between 2008 and 2011 the average yield had increased to more than 1200 Kg/ ha. The area used for cereal production has also increased between 1993 and 2012. Comparing the area harvested in 1993 with the area harvested in 2012 the area has more or less doubled in size. The total production of cereals is two and a half times greater in year 2012 compared to 1993. In terms of total cereal production there has been a big increase. In Amhara region the tef production has almost doubled between 2004 and 2011 and in Oromia the increase has more than doubled. Reasons for this is partly found in the expansion of agricultural area, which has increased by 20 and 30 % in Oromia and Amhara respectively (FAO 2013b; CSA 2013).

3.9 Study areas in South Wollo and South West Shewa

The two study areas in South Wollo and South West Shewa are both located in the Weyna-Dega agro-ecological zone. A majority of the Ethiopians live in that agro-ecological zone which is an important indicator of similar living condition. Farming strategies are very much the same throughout the Ethiopian highlands. Most cultivation is based on rainfall and most farmers depend on oxen for ploughing. Tef cultivation is the most common and important crop in many parts of the highlands, which also is a condition of similarity.

3.10 Study area in South Wollo Kete kebelle (N11.31 E39.68)

The study area in South Wollo is located in the kebelle named Kete (Figure 8). It is located east of the small town of Hayk in Tehuledere woreda. The small but growing town Hayk is an important market town in the area. The location is N11.30 and E39.67 at an elevation of 1940 m.a.s.l. The population of Tehuledere woreda is 174 000 and the population of Kete kebelle is approximately 6600 (CSA 2007). Tehuledere covers 484 sq. km and the Kete kebelle about 12 sq. km.

The seventeen *Gots* in Kete are fairly evenly distributed in clusters. Many of these are located on small hills or along the foot of the slopes. Houses are different in size and the surrounding area is generally a yard with trees such as eucalyptus giving necessary shade for various types of activities. The creek in Kete kebelle is the main source of water in the area. A limited number of farmers, who for a long time have resided in the area next to the creek, are to some extent allowed to use the water for irrigation.

Cambisols are the most commonly found soil type on the hillsides. Vertisols are found in the valley. Vertisols are rich in clay and dry up during the *Bega* season and swells during periods of rainfall. Tef is the most common cereal grown in Kete; Sorghum is the second most common and is grown depending on how rain is falling during *Belg* season. Vegetables are grown and those farmers having irrigation can produce more than one yield per year. The drug Kat or Chat in Amharic is also grown for personal use and as cash-crop. Some households grow coffee, which provides them with a valuable income. The language spoken in Kete is the Semitic language Amharic.

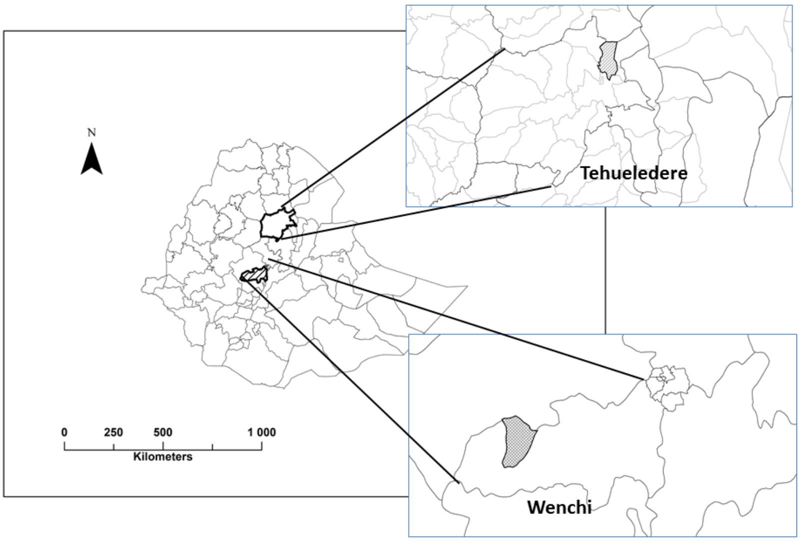


Figure 8. Tehuledere in South Wollo and Wenchi in South West Shewa

Source: GIS Ethiopia, 1999 & USAID Compiled by: Staffan Rosell

3.11 Study area in South West Shewa Wenchi woreda (N08.68 E37.90)

Wenchi woreda is located on the southern slopes of Mt Wenchi north-northwest of the town of Woliso in West Shewa (Figure 8). The latitudinal and longitudinal location is N8.67 and E37.89. The two *Gotis* visited for fieldwork in paper III are located on altitudes ranging between 2100 m.a.s.l. and 2550 m.a.s.l. The total population of Wenchi woreda is approximately 93 000 inhabitants. The area of the woreda covers 461 sq. km. Woliso town is the nearest trading place in the area approximately ten km away.

The study area of Koji is located at 2100 m.a.s.l. in a flat area at the foot of the mountain. Houses are found in clusters where each such cluster represents a small *Goti*. The *Goti* of Chorro, that is one of the two study areas in paper II, is located at an altitude of 2550 m.a.s.l. Chorro *Goti* is surrounded by large gullies formed several decades ago. Farmland is found on the outskirts of the small village, but also between the houses. In Koji and Chorro the staple crop is *enset*, which is often grown right next to people’s houses. On the fields further away from the houses the practise of crop rotation is generally used and crops grown are tef, wheat, barley and maize. Vegetables are also grown in the area. Vertisols are the dominant soil type in Wenchi.

4. Methods and data

Description of methods and data used in this thesis is presented below.

4.1 Seasons of fieldwork

Fieldwork has been conducted on six occasions lasting from one week up to three months Table 1). Fieldwork in South Wollo including soil sampling, semi-structured interviews, transect walks and studying the land use was done twice during the dry *Bega* season. One field visit was done during the month of May and once in October. Wenchi has been visited on three visits during the months of November, March and October.

Table 1: Time of field work

Fieldwork	Year
Reconnaissance trip to study areas	1999 & 2008
Collecting aerial photographs & maps	1999, 2000, 2008
Collecting rainfall data	1999, 2001, 2004, 2008, 2010, 2012
Soil sampling	2000, 2001, 2010
Transect walks & observations	1999, 2000, 2001, 2004, 2012
Interviews	2000, 2001, 2010, 2012

4.2 Climate data

In order to analyse the rainfall change daily rainfall data was obtained from the National Metrological Agency in Ethiopia. The length of the data sets varies in time to due to different time periods recorded at the different stations. The oldest data set is from 1963 and the latest data is from year 2012.

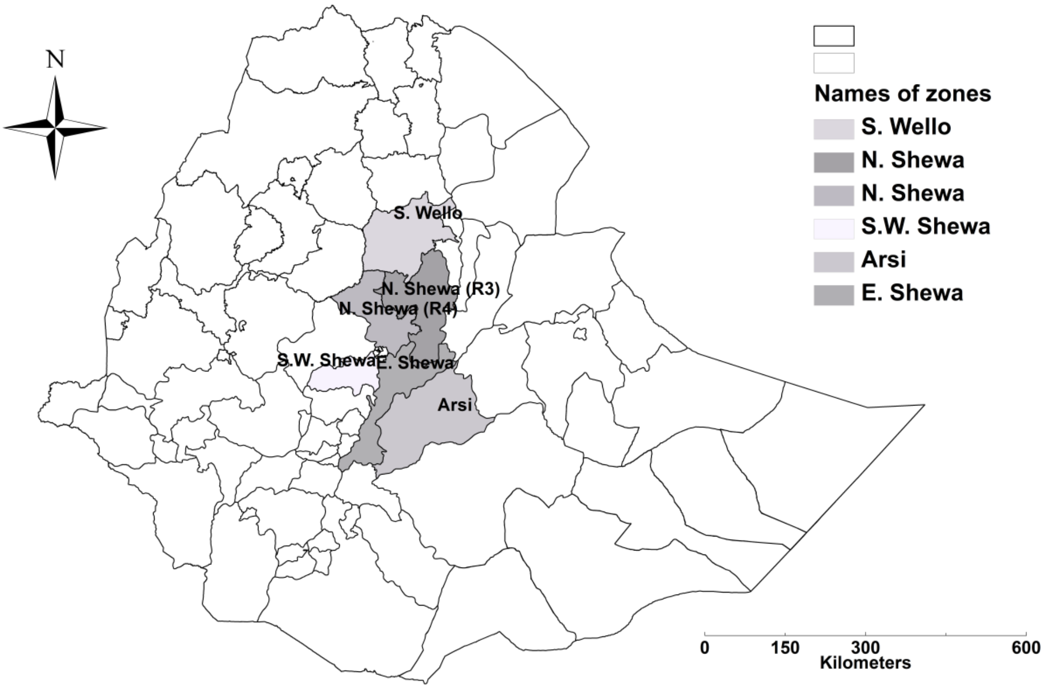


Figure 9. The 13 rainfall stations are located in the following zones of Ethiopia.

Source: USAID Compiled by: Staffan Rosell

Table 2. Daily rainfall data analysed in this thesis are all from the National Metrological Agency in Ethiopia.

Name of Station	Location	Woreda – Zone	Time period
Hayk	N11.19 E39.40	Tehuledere – South Wollo	1963-2012
Kuta Ber	N11.16 E39.32	Kuta Ber – South Wollo	1978-2003
Dessie	N11.08 E39.38	Dessie Zuriya – South Wollo	1978-2007
Combolcha	N11.07 E39.44	Combolcha – South Wollo	1963-2012
Majete	N10.30 E39.51	Antsokiyana – N Shewa	1978-2007
Debre Sina	N9.52 E39.45	Mafud Mezezo/Mojana – N Shewa	1978-2007
Debre Berhan	N9.38 E39.30	Debre Berhan Zuriya – N Shewa	1978-2007
Aleltu AVA	N9.12, E39.09	Aleltu Bereh - North Shewa	1978-2007
Woliso*	N8.53 E37.97	Woliso and Goro – South West Shewa	1984-2008
Kulumsa*	N08.018 E39.16	Ziway Gugda - Arsi	1969-2006
Shashamene*	N07.20 E38.60	Shashamene – East Shewa	1976-2007
Wondo Genet*	N07.08 E38.62	Awassa – East Shewa	1978-2007
Awassa*	N07.059 E38.48	Awassa – East Shewa	1973-2007

*=Data from this station is only covered in the introduction of the thesis. The other stations are analysed in paper I, II and IV.

Analysis of the climate data was done using several methods. In paper I the rainfall data was grouped in two groups each containing 20 years of daily rainfall data. The reason for choosing this method was to reduce any effects of randomness in the data set. In paper II the data was grouped into the three decades. The rainfall and temperature data was also analysed using 5 year moving average. Coefficient of variance (CV) was calculated to analyse the rainfall variability. Number of rainy days (>0, 1 mm), rainfall intensity (monthly rainfall divided by rainy days), total monthly, seasonal rainfall were also calculated. Minimum and maximum temperature daily data from two stations Debre Berhan, Combolcha, and Majete is used in paper I, III and the data from Combolcha is used in the results in the introduction of the thesis. The evaporation model by Thorntwaite (1948) was used to calculate evaporation.

4.3 Soil sampling and analysis

Soil sampling was conducted at households where the head of the household had agreed that soil sampling and analysis could be done. A total number of 73 soil samples was collected and later analysed at the National Soil Laboratory in Addis Ababa. 50 of those samples were collected in Kete kebelle and the remaining 23 were collected in Wenchi. In Wenchi ten of the 23 soil samples were collected in one field used for crop rotation and ten soil samples in one field used for enset in each of the households being interviewed. The remaining three samples were collected along a creek. At each and one of the 73 soil sampling locations nine soil samples were collected. The nine samples were mixed and stirred and then put in one sampling bag for analysis at the laboratory. At the national laboratory all samples were air-dried and sieved. Soil pH, available phosphorous, organic carbon, total nitrogen, cation exchange capacity and soil texture was analysed according to standard methods (Paper II).

4.4 Aerial photographs

Aerial photographs obtained from Ethiopian mapping agency were used when analysing the land use changes in Kete. Aerial photographs from 1958 (V BNRB M73 IEG 3 Jan 58 1, 10842-10845) were used. The aerial photographs were scanned at 2400 dpi and saved as .bmp files. Quantum GIS 2.01 software were used when analysing the aerial photograph of 1958 and also using the plug-in tool fetching Google Earth images from year 2013. A comparison of three land use classes, Hayk town, rural settlement and cultivation, closed area on the hillside slope was conducted when comparing the two images of 1958 and 2013. The aerial photograph was rectified using known locations in Google Earth. The number of locations was 105 in total for each image. Analyses of land-use of the two *Gots* of Dinso and Merfo was conducted and a total of six different land use types were identified, cultivation, settlement areas, eroded area, grazing, perennial crops and tree-covered areas. Each of the land use types was digitized and the area of each type was calculated in QGIS 2.0. In the satellite images the colours of the fields appears as shades of green depending on the vegetation cover, or brown if there is bare soil after harvest or before planting. Very often a lighter colour nuance is found between the fields, which reveal some type of soil and water conservation measure such as terraces. Signs of erosion usually appear as lighter spots in cultivated fields and more severe erosion such as gullies can be identified as light coloured single or multiple channels running along the slope. Trees have round canopies and are usually found around houses. The high reflection of the tin-roofed houses makes them easy to identify. The traditional houses with grass roofs can be identified by their round shapes.

4.5 Transects and physical observations

Transect walks were conducted during fieldwork in 2001 (Figure 10). The topographical map Ethiopia 1:50 000 ETH 4, 1139 D1 (Ethiopian Mapping Authority 1993), 1993 was used for demarcation of the sub-catchment of the study area of Kete kebelle. Fifty possible transects 100 m apart were identified; 25 on the northern and 25 eastern slope. Five transects were randomly chosen on each of the two slopes. This was done by using the Microsoft Excel random-number generator. Along each transect a random distance of 50 up to 350 meters were randomly generated; the reason for this was to avoid conducting measurements twice in the same field. A handheld GPS was used for navigation and to find the observation points. Totally 107 points were studied. Observations of different types of land use were conducted and the following classes were found: cultivation, rural settlement, signs of erosion, grazing, soil type, soil and water conservation techniques used and pathways. The east-west transects started close to the river and the north-south at the foot of the hill and ended where the cultivation ceased uphill.

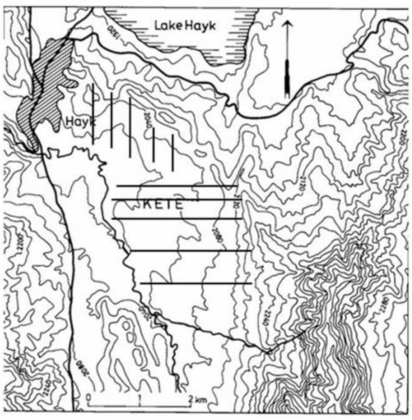


Figure 10. Map of transects in Kete kebelle

Source: (Ethiopian Mapping Authority 1993)Compiled by: Solveig Svensson

4.6 Interviews and informal discussions

During all field trips to Ethiopia, meetings and exchange of information has taken place with people. Information that has been of use for this research project have been gathered while meeting Ethiopian employees at authorities, University of Addis Ababa, local administrative offices, local agricultural offices among others.

Forty structured interviews with the head of the household in each household which lasted for about one hour each were conducted. A questionnaire was used during all interview sessions, but when the circumstances required follow up questions and discussions were done to clarify the answers. The questions focused on farmers' assets such as land, access to oxen, labour and their perception about rainfall, soil productivity and advantages and constraints with farming in the area. A random process to single out four households along each to the ten transects were used after the transect walks. This was done to have a representative selection of household for the interviews. Shorter interviews were also done with farmers having irrigation along the creek. The total number of interviews with farmers having access to irrigation was 15. Group interviews with school children were held at the primary school in Kete kebelle. Each group contained five boys or girls aged 11-14. In total six groups of five children in each group were interviewed. Once again a random process that made it possible to single out five children from each of six classes in school.

During the field work in Wenchi (Paper II), two group interviews were conducted. Five heads from different households in each of the two studied *Goti*s in Wenchi were identified and asked to participate in a structured group interview. The questionnaire focused on the type of soil, size of area for cultivation, type of crops cultivated, food security, soil erosion, and advantages and disadvantages that the farmers experience being farmers.

5. Results

5.1 Rainfall changes

The results are presented in the following order; firstly the climatic results are presented followed by the results on the soil analysis and thirdly the analysis of the land use changes. The results found under the heading Rainfall change between Awassa and Hayk (Figure 10) are not included in any of the five papers. The remaining part starting from 5.1.2 of the results is based on the five papers in the thesis.

5.1.1 Rainfall change between Awassa and Hayk

In figure 11 the yearly and *Belg* rainfall is shown over a larger area than covered in paper I & III from Awassa in southern Ethiopia up to Hayk in northern Ethiopia. This is done to further understand the large scale changes and differences of rainfall in the central pars of Ethiopia where *Belg* rainfall is vital.

Yearly rainfall is slightly higher at the northern stations compared to the southern stations in figure 11. The *Belg* season rainfall varies between the stations. Debre Sina and Wondo Genet receive the highest amount of rainfall during *Belg* season. Woliso and Debre Berhan receive the lowest amounts of rainfall during the *Belg* season, both located in the central part of the 13 rainfall stations. *Belg* rainfall plays a vital role of the total precipitation of all the 13 stations analysed. In Woliso though it only makes up around 6 % of the yearly rainfall and on the other hand in Shashamene and Wondo Genet it produces 40 % respectively 38 % of the yearly rainfall.

In terms of variability, that is calculated using the Coefficient of variance (CV), stations up north have an average of close to 40 and the southern stations around 30. This means that *Belg* rainfall has got a higher variability in the northern stations. This shows that most northern stations have less rainfall during the Belg season which is a disadvantage for the farmers' that are dependent on rain-fed agriculture.

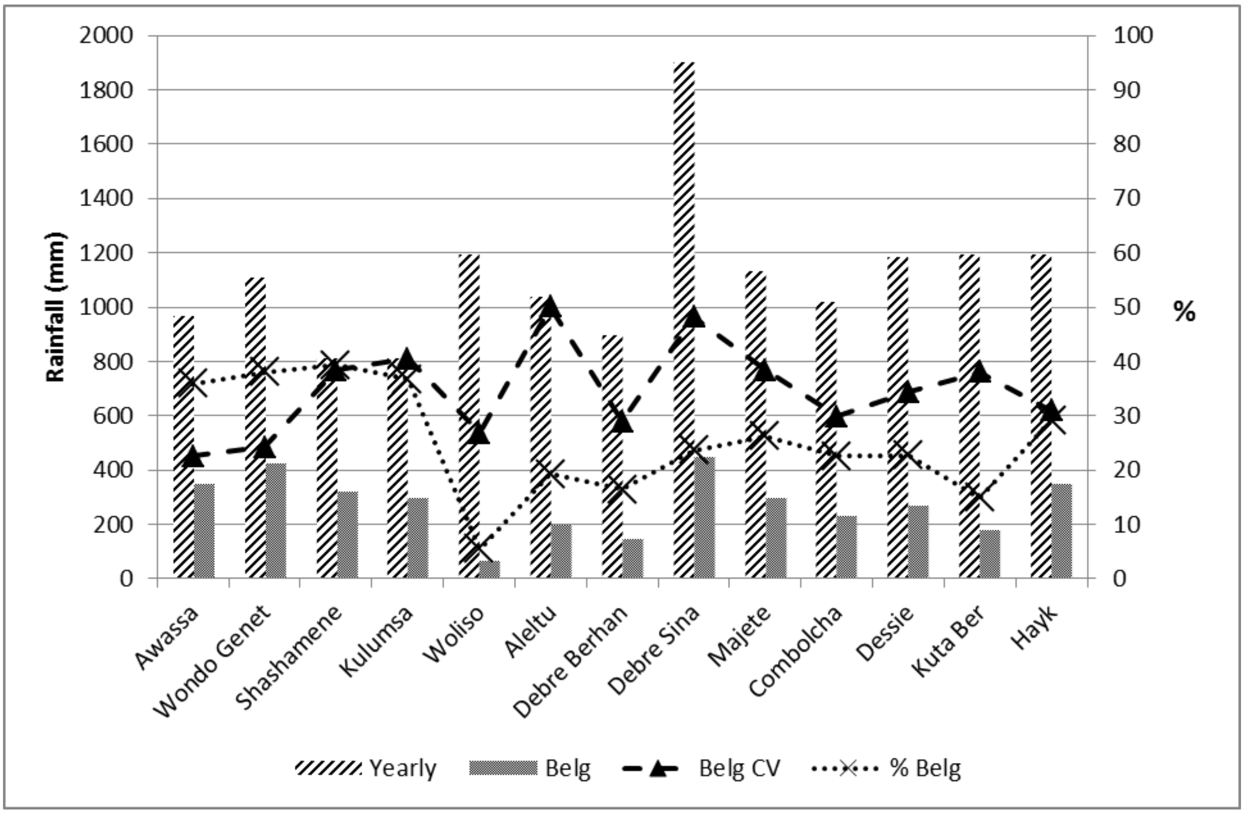


Figure 11. Yearly & *Belg* rainfall 13 stations from south (left) to north (right). CV (Coefficient of variance) and percentage *Belg* rainfall of yearly rainfall.

The decline in *Belg* rainfall after 1996 is shown in figure 12. In figure 12 rainfall data indicates that *Belg* rainfall has been below average at all but one station analysed when comparing *Belg* rainfall between 1984 and 1996. The average rainfall for the two time periods is compared with average for the full period. It is worth taking note of that at Awassa there is no difference. Six stations only received 80% or lower of the average rainfall for the full time period. This shows that the findings in Paper IV from Combolcha and Hayk are also visible throughout the central parts of Ethiopia between Awassa and Hayk which is a distance of approximately 600 km.

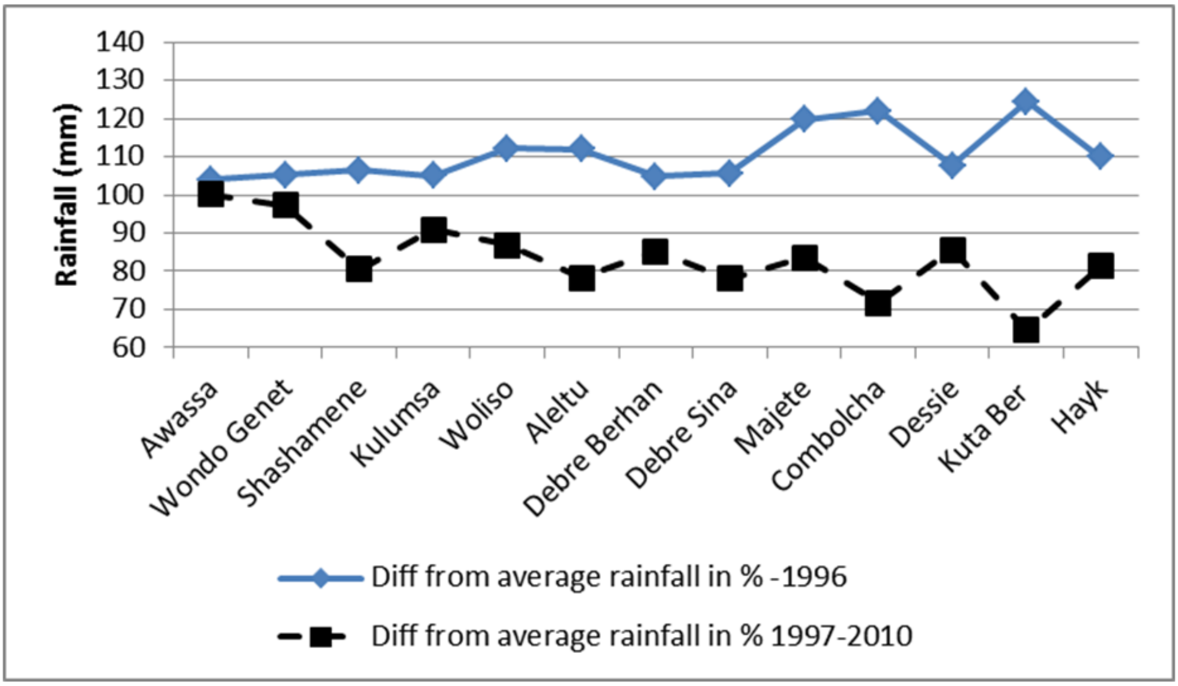


Figure 12. Difference from average *Belg* rainfall in percentage Awassa to Hayk comparing 1984- 1996 & 1997-2010

5.1.2 Rainfall change in the central highlands (Paper I, III, IV)

In paper I when comparing three decades (1978-2007) the variability of the *Belg* rainfall indicated no increase. The same can be said about the variability of the long rainy season *Kiremt*, but the short dry season *Bega* showed large difference between the three decades. Comparing the three decades regarding variability during *Bega* season it varied between 49 and 75.

In paper IV a striking decline of *Belg* rainfall from 1996 has been shown (Figure 13). In Hayk a recovery of the *Belg* rainfall is evident but in Combolcha a low level of *Belg* rainfall continued until 2012. This drop in *Belg* rainfall is analysed in paper V. Between 1963 and 1996 variations in *Belg* rainfall correlates at both stations. An example of this is that both

Combolcha and Hayk had the largest amount of rainfall in 1994 and both stations had low amount of *Belg* rainfall in the 1970´s.

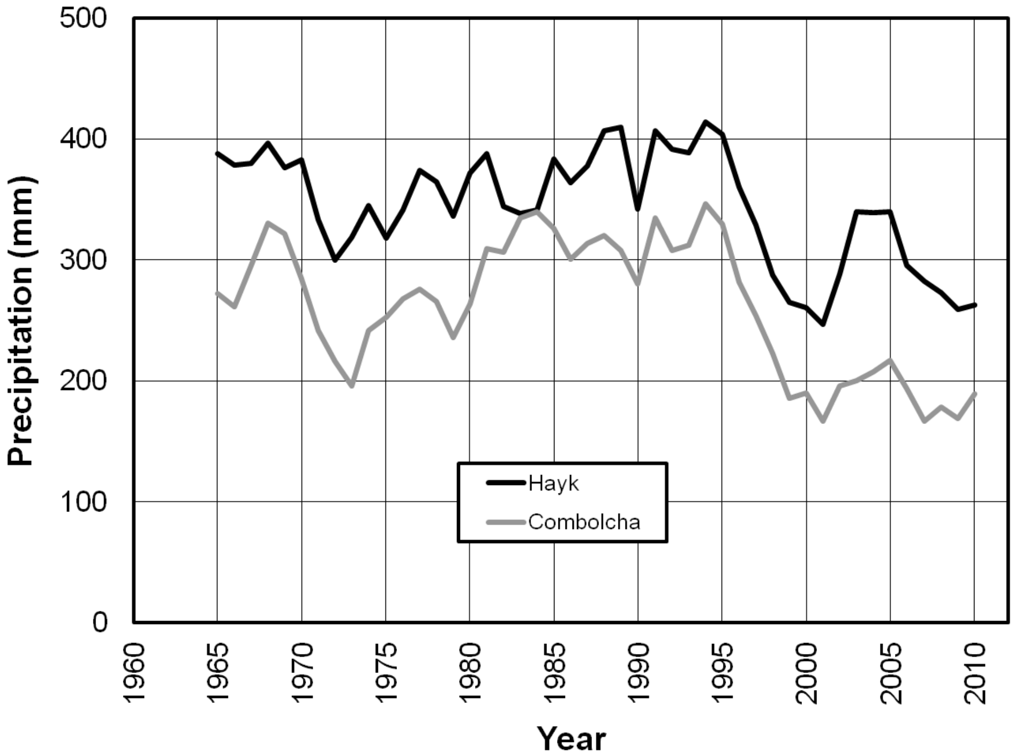


Figure 13. 5-year moving average of rainfall in Combolcha and Hayk

5.1.4 Start of rainy seasons (Paper I)

The start of the rainy seasons is important because it determine the time of the sowing and planting of cereals and vegetables. In the northern highlands the time period between the start of the *Belg* rainy season and the start of the *Kiremt* season is a growing period of importance for the farmer's food security. Figure 14 shows the number of days between the two rainy periods comparing three decades (1978-2007). The average number of days between the short and the long rainy season varied between 83 days at Aleltu to 124 days in Hayk. This means that the possibilities to grow tef during the *Belg* season is difficult at some locations with the fact that tef needs 90 days to mature. Farmers need to harvest the tef in time before the *Kiremt* season starts.

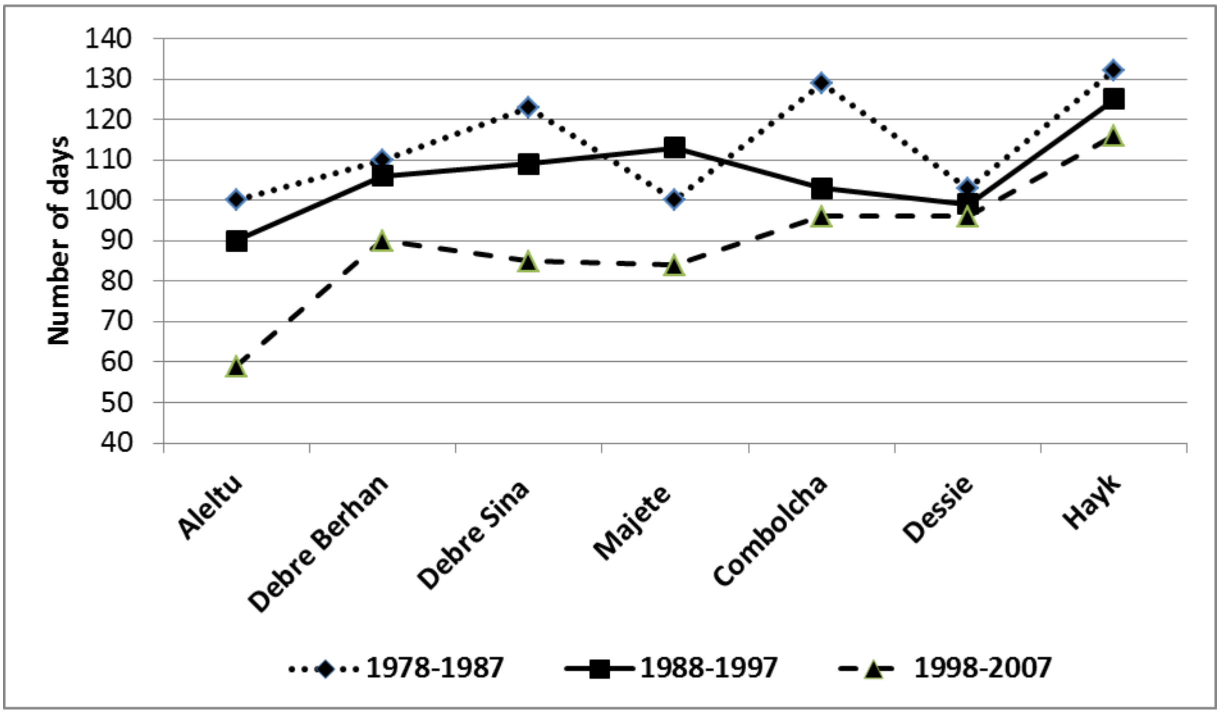
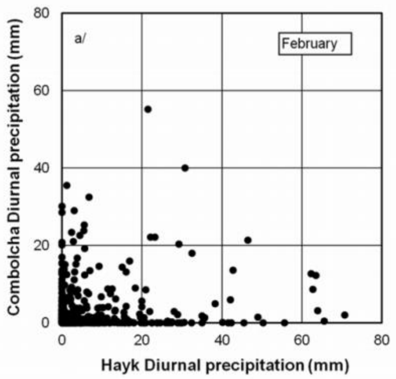


Figure 14. Number of days between *Belg* and *Kiremt* season

5.1.5 Erratic rainfall (Paper IV)

In figure 15 it is shown how the early *Belg* rainfall differ compared to the early *Kiremt* rainfall in Combolcha and Hayk. In February it is visible how there is only rainfall at one of the two sites on the same day. In February there is only 161 days of the total 400 rainy days that there is rainfall both in Combolcha and Hayk. In July there is 917 days with rainfall at both stations of the total 1236 rainy days.

There are few rainy days at any of the two stations. A majority of the days have no or little rainfall, compared to early *Belg* rainfall the early *Kiremt* rainfall shows high number of rainy days at both stations.



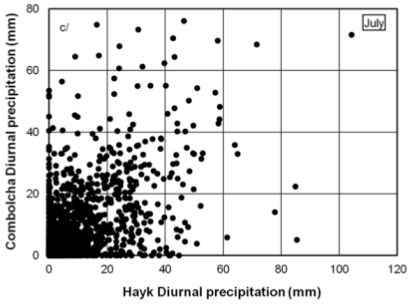


Figure 15 a & b. Relations of daily precipitation in Combolcha and Hayk 1964-2012 in a) February & b) July.

5.1.3 Air temperature (Paper I)

The average temperature in Combolcha located 30 km south of Hayk but on the same altitude varies between 17˚ C and 23˚ C (Worldclimate 2013). Temperature data from Combolcha station indicates that the temperature during the *Belg* season (February-May) in Combolcha has increased regarding the maximum temperatures of almost two degrees Celsius between 1957 and 2010. The minimum temperature indicates no increase during the time period 1957-2010. There has been variations over the years both regarding minimum and maximum temperatures. The higher temperature suggests an increase in evaporation. The decline in *Belg* rainfall and the increased temperature means that there is less water available.

5.1.6 Impact of rainfall change on *Belg* harvest (paper III & IV)

In paper III the results show the importance of *Belg* rainfall in Tehuledere. The *Belg* rainfall makes up just over 30% of the total yearly rainfall, but its importance for the total food production must be emphasized. The rainfall model used in these papers was developed after key informants told if they were able to harvest tef or not in *Belg* season during the past nine years. Of the 40 years analysed only 18 years were suitable to grow tef during the *Belg* season. All three criteria in the rainfall model must be fulfilled for a successful tef harvest. In paper IV shows a decline in total rainfall during *Belg* is shown, but rainfall and also an increase in dry spells. These changes have a negative influence on the possibilities to grow tef during the *Belg* season.

In Paper IV the criteria´s were modified. Some of the criteria´s were changed, e.g. the number of dry days after sowing was increased to nine days, and the amount of rainfall during the start of the rainy season was increased to 25 mm instead of 15 mm of rainfall with the same result as the previous criteria. Instead of having a certain amount of rainfall during February, March and April the new criteria was set to 130 mm of rainfall the month after sowing. This was all done to improve the rainfall model for tef cultivation. The time period covered in Paper IV is 48 years between 1964 and 2012.

There are three basic rainfall criteria that have to be fulfilled: Paper III

1/ Start rainfall - enough rainfall to sow: at least 25 mm in three days of which at least two have rainfall.

2/ No drought - no drought directly after sowing: drought is defined as 9 consecutive days without rainfall.

3/ Wet month - enough rain the month after sowing: rainfall of at least 130 mm.

Figure 16 shows that there were only 10 out of 48 years that Combolcha and Hayk had the possibility to harvest tef the same year. Potential harvest occurred during 18 of the 48 years at one of the two stations, which means in total 28 out 48 years with a potential tef harvest. Growing tef during the *Belg* season is difficult, only every second year is successful at the two stations. This is also an indicator of how big the difference in *Belg* rainfall is between two adjacent places like Combolcha and Hayk.

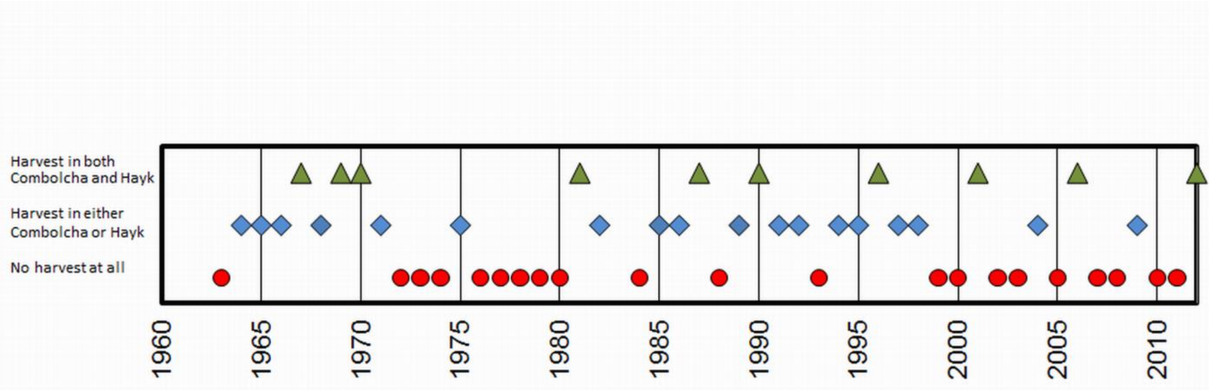


Figure 16. Synchronicity of simulated harvests

5.2 Soils, land use changes and farmers constraints

The results regarding soil parameters, land use changes, farmers assets and farmers perception of the constraints the farmers are dealing with are presented below.

5.2.1 Soil parameters (Paper II)

Soil parameters that play a vital role for crop growth are important for farmers in rural Ethiopia (Table 3). People have an opinion and strategies to improve and maintain the level of nutrients in the soils. Farmers use crop rotation if possible, farmers use manure and ash to apply on the fields. The method of leaving land in fallow is also widely known as a positive method to improve or maintain soil productivity. In Tehuledere the general picture that farmers gave was that soil fertility was low and has declined during the past decades. In Wenchi answers varied more and the soils in the low-lying *Goti* named Koji was considered having good soil fertility. In Chorro on the hillside, soil fertility was a problem according to the farmers. Food aid does exist in Tehuledere from time to time. At the end of the *Kiremt* season the farmers claimed that they have problem with food security before harvest season. If *Belg* season fails the problem with food security increased according to the farmers.

Three of the twelve soil parameters analysed showed a significant difference between Tehuledere and Wenchi. The three soil parameters are CEC, C/N ratio and Organic Carbon.

The organic carbon show very low values in Tehuledere, around 1%, and showed much higher values in Wenchi compared to Tehuledere, but still fairly low values of around 3%. The C/N ratio and the CEC values which also showed a significant difference are more positive for plant growth in Tehuledere than in Wenchi. Those three parameters, CEC, C/N and O.C. are all three important for agricultural production (Table 3).

Table 3. Soil parameters in Wenchi and Tehuledere

	pH H2O 1:2.5	**EC ds/m**	**Na (Cmol (+)/kg**	**K (Cmol (+)/kg)**	**CA (Cmol (+)/kg)**	**Mg (Cmol (+)/kg)**	**Sum**	**CEC (Cmol(+) /kg)**	**Bas.Sa %**	**T.N. %**	**O.C. %**	**C/N**	**O.M %**
Wenchi	6.6	0.17	0.1	2.9	13.8	3.9	21.9	30.6*	70.5	0.3	2.95 *	11.7*	5.1
Tehuledere	7.1	0.07	0.3	0.9	30.0	10.9	43.5	50.3*	92.5	0.1	1.1*	9.8*	1.8

Significance difference *0, 05

When comparing samples between enset fields and crop rotation fields in Wenchi, there were eight different parameters that showed a significant difference (Table 4 & 5). The ones that did not indicate any significant difference are Ph, EC and Na. The enset fields have a better potential for crop growth when analysing the parameters for soil productivity. The organic matter % in the enset fields must be considered good with values close to 7 %.

Table 4. Enset and crop rotation

	Ph H2O	EC	Na Cmol (+) Kg	K	Ca	Mg	Sum
Enset	6.9	0.3	0.1	5.8*	17.6*	4.4*	29.5
CR	6.6	0.2	0.1	1.8*	12.4*	2.5*	16.3

*sig difference 0.05

Table 5. Enset and Crop rotation

	CEC	Bas. Sa	T.N. %	O.C. %	C/N	O.M. %
Enset	33.3*	88.5*	0.3*	4.0*	12.5*	6.9
Crop rotation	27.6*	60.5*	0.2*	2.5*	10.7*	4.2

*sig difference 0.05

5.2.2 Farmers perception of agricultural constraints (Paper V)

The farmers' perception of their situation is based on interviews. All farmers claimed that there has been a decline in yield over the past decades. Reason for this decline was found in rainfall. Rainfall has become more erratic today than it used to be according the farmers. Findings by Bewket and Conway (2007);Paper I; Paper III confirm these findings not only in Hayk but also at other locations in Amhara region.

Loss of soil fertility was also mentioned as a parameter influencing the decline in crop yield. The low amount of organic carbon of 1 % that is found in Paper II is very low and has a negative impact on crop growth. Only 15% of the respondents mentioned the small farm areas as a problem. The ability to sell cash-crop at the market was mentioned as a big advantage by a quarter of the respondents. The farmers having irrigation along the creek in Kete kebelle claimed that the reason for starting this irrigation was the dry conditions during 1998 and they stressed this as an opportunity to increase the income by selling cash-crop such as vegetables at the nearby market place in Hayk town.

5.2.4 Land use changes and farmers adaptation (Paper V)

The following part deals with the results of the interpretation of aerial photographs from 1958 and satellite images from 2003 and 2013. The land use and land cover changes (LULC) of the following land use classes: cultivation and rural settlement, non-cultivated area and protected area, annual cultivation, perennial crops, tree-covered area and Hayk town.

The land use in Kete is limited to approximately 1527 ha (hectare). Within that area the hillside of Gadera ridge (protected area) is of very limited advantage for the farmers. Grazing animals can be found at the lower parts of the hillside slope. The town of Hayk has increased it proportion of the total land area of Kete since 1958. During this time period, between 1958 and 2013, there has been a population increase which has reduced the available land per capita (Table 6). According to response from the head of households in the Kete the households´ farm area in Kete kebelle is varying between 0.1 ha and 0.6 ha. The median value is 0.32 ha and five of the 40 households, where head of household were interviewed, have an area larger than 0.4 ha. Six households have land less than 0.2 ha.

Table 6. Land use changes in Kete kebelle 1958 to 2013.

	1958	**2013**
Area for agricultural purposes	88%	85%
Hayk town	3	8
Protected area	9	7

Kete kebelle is located in the lower parts of the valley which is located in a south to north direction (Figure 17). The eastern slope of the Kete is found on the Gadera ridge which has a peak at 2500 m.a.s.l. The town of Hayk is slowly growing in all four directions around the centre of town.

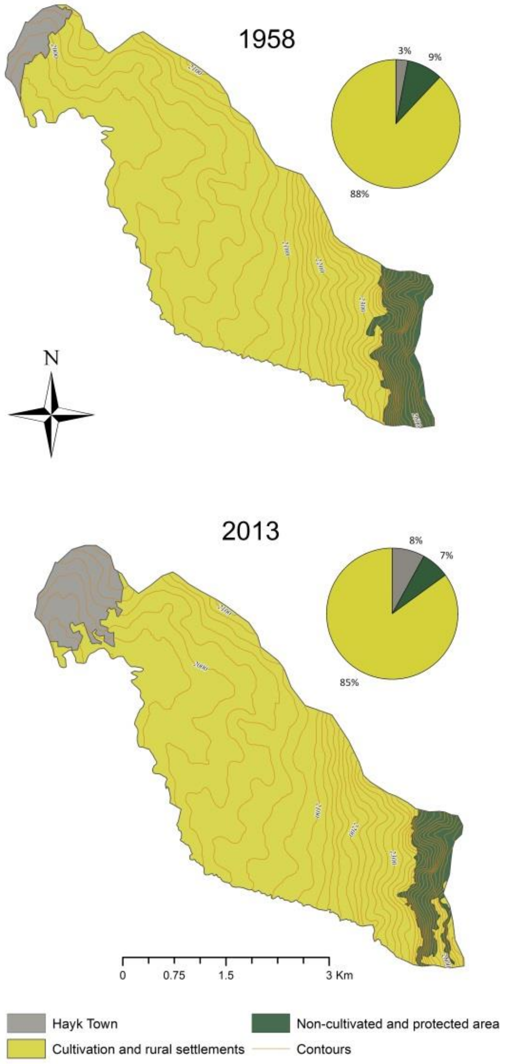


Figure 17. Land use in Kete kebelle in year 1958 & 2013.

Compiled by: Mats Olvmo

Figure 18. Photo of a water harvesting pond in Kete kebelle.

Photo: Staffan Rosell

Figure 19 shows the changes in Dinso between 1958, 2003 and 2013. A concentration of the areas used for settlement is visible. The settlement covers 19 % in 2013 of the area compared to 11.5 % in 1958. On the map from 2003 it is worth taking note of perennial crops which was not visible on the aerial photograph from 1958. In year 2013 perennial crops covered 5 % of the land area. Another important change in land-use is found on the map from 2013, the introduction of water harvesting ponds which can be counted to 15 that year. They were introduced in 2009 in Kete village (Table 7). The initiative was subsidised by the local authorities. Plastic sheets put at the bottom of the man-made holes dug for water harvesting was a change in the farmer´s opportunities to improve food security, and a possibility to bring in cash to the households in a completely new way.

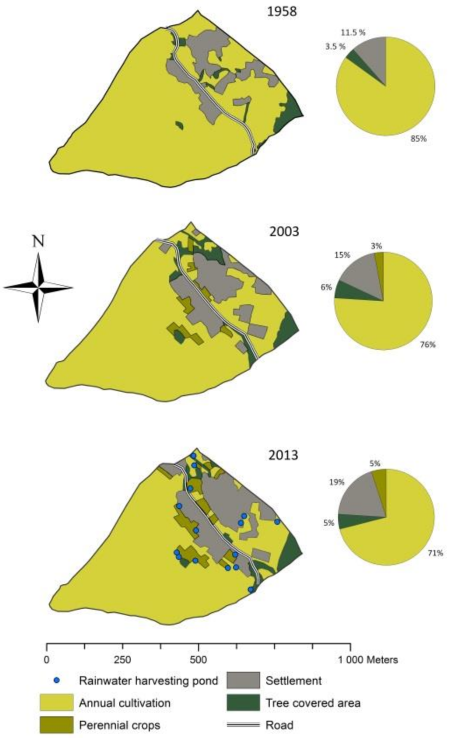


Figure 19. Land use Dinso got comparing the years 1958, 2003 & 2013.

Compiled by: Mats Olvmo

Table 7. Land use in % in Dinso got 1958, 2003 and 2013.

	1958	**2003**	**2013**
Cultivation %	**85**	**76**	**71**
Perennial crops %	**0**	**3**	**5**
Settlement %	**11,5**	**15**	**19**
Tree-covered area %	**3,5**	**6**	**5**

In the case of Merfo cultivated area has also decreased and the settlement area has increased (Table 8). Just as in Dinso perennial crops has increased and the water harvesting ponds are also nowadays found in the land use. It is also worth taking note of the increase of trees in Merfo.

Table 8. Land Use & Land Cover (LULC) in Merfo in 1958, 2003 and 2013 (%).

Merfo	**1958**	**2003**	**2013**
Cultivation %	89	81	75
Perennial cultivation %	0	2	6
Settlement %	6	7	8
Trees %	5	10	11

6. Discussion

Spatial and temporal changes of rainfall, soil productivity and parameters such as land use will be presented in the discussion. The discussion is based on the results from the five papers in this thesis and also the new results regarding rainfall between Awassa and Hayk presented in the result section.

6.1 Rainfall changes and tef cultivation

The decline in *Belg* rainfall after 1996 shown by Bewket (2009); Viste et al. (2012) is found at all but one of the 13 stations analysed in this thesis (Figure 11). The exception is the southernmost station of Awassa. The yearly rainfall on the other hand has increased at the most of the northern stations and decreased further south. Also in this case Awassa is an exception with an increase of yearly rainfall in contrast to the other stations in the south. The decline of *Belg* rainfall found in Paper I which covered seven of the most northern stations can also be confirmed further south in Ethiopia.

The differences in *Belg* rainfall change found in Paper I emphasise the importance of understanding the local differences in rainfall distribution and how this influence the farmers' situation in the central highlands of Ethiopia. The rainfall distribution during the past 30 years between Aleltu and Hayk shows that the farmers have a more difficult situation in the northern part of the study area due to the higher percentage of farm land used for agricultural production during the *Belg* season. This indicates that the *Belg* harvest is more important in a food security perspective in the northern part of the study area compared to the southern part. In addition to the dependency on the *Belg* rains the shallower soil cover, the steep topography and the higher population density in the north also lead to a more vulnerable situation compared to the southern part (Paper I).

The decline in *Belg* rainfall during the latest of the three studied decadal (1978-2007) periods (Paper I) might influence the possibilities to grow tef during the *Belg* season, but our rainfall model for tef cultivation shows that the starting time as well as the dry spells and the amount of water during the early stages of the growing season are more important than the total amount of rainfall. The dramatic decline in *Belg* rainfall since the mid 1990´s and the decreased possibilities to grow tef has created a different situation for the farmers in the two adjacent places Combolcha and Hayk. This emphasises the importance of conducting local studies to understand the situation for farmers, which obviously differs from one valley to another.

A change in air temperature was also found when analysing the long term trend at Combolcha. Conway et al. (2004) found an increase in minimum air temperature of 0.4 C per decade at Addis Ababa stations since the 1950´s and an increase in air temperature of 0.2 C per decade. The decline in *Belg* rainfall in combination the higher air temperature results in higher evaporation has resulted in a decreased amount of water available for the plants for the farmers dependent on rain-fed agriculture.

It is also shown that the *Belg* rainfall has changed since the 1960´s. It has become more erratic and dropped dramatically at the two stations Combolcha and Hayk. Since the mid 1990´s, this change has also been found at other stations in the Amhara region where the two stations of Combolcha and Hayk are located, but also at other sites in the country (Bewket 2009; Viste et al. 2012). When comparing the *Belg* rainfall during three decades (1978-2007), the time period 1998-2007 indicate the lowest amount. In contrast the increase of the *Kiremt* rainfall is highest during the latest of the three ten-year periods (1998-2007) compared.

The data shows that the 1970´s was a dry decade and that rainfall increased in the 1990´s. This is in line with findings by (Bewket and Conway 2007; Nicholson 2000; Shanko and Camberlin 1998).
Farmers' perception that rainfall has become more erratic is confirmed by the data analysed in this thesis (Paper I, III and IV) in addition it is not only around Hayk that rainfall has become more erratic, but also in the central Ethiopian highlands in general. The farmers' perception of the rainfall is based on the interviews, which have been conducted with interpreters and guides in the field. Maybe another interpreter would have translated comments differently and if having knowledge of the local languages, Amharic and Oromo, the understanding and nuances of the answers could have been better. This was not the case and the fact that I had a reliable and good interpreter on every field visit made me believe that the answers from the villagers were trustworthy.

The uncertainty concerning the onset of the rainfall implies that the farmers need to be flexible regarding sowing times. When the *Belg* rain starts later than expected there will be less time to harvest and prepare the land before the *Kiremt* season starts. The fact that only two out of three farmers in Kete village has got access to oxen of their own is important. Those farmers without oxen and those who have limited access to labour in the household are more vulnerable when there is a high pressure to act fast during harvest and ploughing seasons. In rural Ethiopia, women find themselves in a difficult and unfair situation compared to men. One of the most serious disadvantages for women is the tradition of not being allowed to use an ox for ploughing. For women not having access to an ox, share-cropping is the way to cultivate their fields. Share cropping means that the harvest is shared 50-50, with the man who takes care of the ploughing. Female-headed households having a brother, son or access to male labour is equal to male-headed households (Nässen 2009).

The yearly or seasonal rainfall amounts do not indicate the potential to harvest tef (Paper III). This was the starting point for developing the rainfall model for tef cultivation (Paper III & IV). The rainfall model was modified in Paper IV, and is based on the farmers' answers whether they were able to harvest tef or not in Kete kebelle during the past nine years. There was no discussion of quality or quantity, just a basic yes or no. This gave an opportunity to analyse the rainfall data in depth over the past 40 years to find a pattern when tef harvest was successful or not. The results show the importance of analysing daily rainfall data in detail. A late start or a long dry spell after sowing showed that those parameters had a larger influence on tef harvest than the total amount of rainfall during the *Belg* season. The results show that the farmers were able to harvest tef 9 out of 20 possible years during both of the two twenty-year periods (1963-1982 & 1984-2003). This shows how vulnerable and risky cultivation is for the farmers in Kete. On the other hand harvest figures such as yield per capita and the total production of cereals has increased in Ethiopia (CSA 2013; FAO 2013a). Similar response is found in East Africa where an increase of approximately 60% on the maize yields is found during the past 50 years. The same increase is found when analysing Sorghum yields which also has increased during the past decades in East Africa (FAO 2013a). Future scenarios of cereal production in Ethiopia looks bound to decline according to Evangelista et al. (2013), who presents findings that suggest a decline in crop yields due to the impact of increased air temperature and more extreme events of rainfall on four different cereals, tef, maize, sorghum and barley.

Having only one tef harvest every second year is of course a disadvantage and puts pressure on the farmers food production with a harvest failure every second year. Farmers in South Wollo struggle with malnutrition and food shortage has been common throughout the region for a long time. Since 1995, the area around Hayk has been in need of food assistance between five to eight times (DRMFSS 2013).

The changes in rainfall intensity, the number of rainy days, the distribution of rainfall during the rainy season and the dry spells are details that were unveiled when studying the changes of daily rainfall and the possibilities to harvest tef or not during the *Belg* season (Paper I & III). On the other hand, there are years which had very low amounts of rainfall during the *Kiremt* season e.g. the year of 1984, which was a dark year in the history of Ethiopia. Low *Kiremt* rainfall was followed up by low *Belg* rainfall which caused a tragic famine among millions of Ethiopian farmers in the central highlands.

6.2 Soil parameters and Land use changes

Analyses of soil parameters are important when studying the advantages and constraints for food production farmers have to deal with. Soil parameters influencing the soil productivity such as parent material, topography, climate, land cover and human activity among others are influencing the soil status, varies within Ethiopia both at regional and local scale. The productivity can be described as the capacity of a soil to produce crops. The inherent capacity of a soil to supply the following: nutrients, minerals, water and air to the rooting system of plants (Jones et al. 2013). The comparison between Tehuledere and Wenchi were valuable in helping to understand the differences of soil parameters between enset and tef based cropping strategies (Paper II).

The possibility to compare the soil productivity in Tehuledere with a location on the same altitude, similar annual rainfall and production of tef, gave an opportunity to understand and analyse the problems that farmers to sustain crop production at a greater scale than just an analysis of Hayk (Paper II). The comparison of Wenchi and Hayk showed that the low content of organic matter is a disadvantage in Hayk from a soil productivity perspective. In other studies such as Coorbeels (2000); Pan et al. (2009); Tisdale (1993) it was found that organic matter is important for crop production. The actual impact this has on the size of the harvest is difficult to predict since the size of a harvest is influenced by rainfall, crop varieties and soil conservation among other parameters (Simelton 2007). It is however documented that an adequate level of organic matter in the soil is important to preserve soil fertility (Jones et al., 2013). The organic matter increases water holding ability and strengthen the soil structure which also helps to improve permeability and ability to hold water (Jones et al., 2013).

No significant difference between Wenchi and Hayk was found regarding other parameters of interest for soil productivity. The findings that enset cultivation show soil parameter values more suitable for cultivation compared to the crop rotation fields is an important finding. The explanation of the significantly higher levels of e. g. organic matter may be that farmers more easily can add organic matter in the enset fields that often are accessible nearby the houses compared to the fields further away. This is in line with findings by (Moges and Holden 2008).

The land use changes in Kete kebelle that was found between 1958 and 2013 are important to analyse in order to understand the constraints that the farmers are dealing with (Paper V). The increased pressure on the land is most likely due to a higher number of houses, which probably is a result of a population increase. The population has increased from 21 million in Ethiopia since 1958 to around 87 million people in 2013 (UN.org 2013). The population in Kete has increased from around 1900 in 1958 to approximately 6600 in year 2013 (CSA 2007, 2013).

There is a greater pressure on the land, and the farm areas are smaller than they used to be. The analysis of land use changes in Dinso and Merfo reveals that areas used for housing have expanded and there is a decline in areas used for cultivation. In the late 1950´s, 93% of the population lived in rural areas whereas today 83% of the population lives in the rural parts of Ethiopia (ESA.UN 2013b; FAO 2013a). The growing urban population is in need of inexpensive food, and with an increase in urban population a surplus produced in rural areas is necessary.

The fields with perennial crops that are visible in the satellite images from 2003 and 2013 may be used for Khat production which is an important cash-crop sold at the local market. Cultivation and trading of Khat is considered a good source of income according to the farmers in Kete. The number of houses, which has increased made the settlement area more densely built-up. There were only few new houses in the cultivated areas. This shows the efforts spent in preserving cultivated land. Farmers prefer to concentrate the houses instead of using valuable farm land. Several studies of land use changes in Ethiopia tell about the removal of tree-covered areas and shrub-land that is turned into agricultural land (Amsalu et al. 2007; Bewket and Abebe 2013b; Dessie 2007; Getachew and Melesse 2012; Tegene 2002). Most of these studies cover larger areas compared to the Kete kebelle. The fact that no one had any land in fallow since the days of Emperor Haile Selassie (1892-1975) is an example of the intensification of the use of farm land in Kete.
Farm land is limited and the importance of maintenance of the cultivated land can´t be emphasized enough. In a study of the central parts of Ethiopia (Bantider et al. 2011) found that soil conservation techniques are most important and can improve the soil quality and the size of the crop yields. The farmers' knowledge and understanding of the impact of soil erosion on crop yield as well as the effect of soil and water conservation methods (SWC) is very important and may significantly reduce the negative trend of decline in harvest (Bekele and Drake 2003). Asrat et al. (2004) show that farmers were willing to spend time and working hours on SWC, but farmers' willingness was also correlated to education level. Farmers with higher education were more willing to spend money on SWC than those less educated. Bewket and Sterk (2002) found that farmers´ involvement as well as practical information from local authorities and training in the field are most important factors to get people interested in using the soil and water conservation techniques. Today, in Ethiopia as a whole, the most common processes of erosion are sheet and rill erosion (Gebrernichael et al. 2005). In the highland areas, gully erosion is also a threat to the environment, which has a negative impact on farmers' livelihood situation (Moges and Holden 2008). It is important to improve the land management and to slow down degradation and make land use more

sustainable. This situation can be improved if the socio-economic condition in the country is strengthened (Nyssen et al. 2004).

In 2009 the new technique of water harvesting was introduced in Kete (Paper V). Those water harvesting ponds are used for watering of Khat fields. This strategy of using the water for Khat cultivation should be evaluated after a few years. With lack of food and high price on tef, which is three times higher than before the food crisis in 2008 (FAO 2013b) it might be a better option to use the water for growing tef in the long run than growing Khat. Dessie (2013) found that Khat growers were economically very strong compared to farmers not involved in Khat production. On the other hand, Khat growing lead to income disparity and food insecurity since food crop often is replaced by Khat. In addition the mono-cropping system makes households more vulnerable and dependent on income from one crop.

Between 2001 and 2012, the small irrigated area along the Kete creek has increased from 29 ha to 41 ha. There is a limitation to the size of irrigated area due to lack of power driven pumps. The water is led up by a small canal, and water can only enter the area after rainfall when the water level is high enough to enter the canal. This has resulted in farm land being washed away, and farmers that suffered from loss of land have not been offered any replacement. In a national perspective Ethiopia can develop the irrigation from a level of only 0.7 million ha (MHA) to 5.3 million ha (Awulachew and Ayana 2011). Both these figures are much higher than the 0.29 MHA reported in 2001 (FAO 2013a).

7. Conclusions

Today the farmers are under greater pressure to diversify their cropping strategies and to find ways to access water, like building water harvesting ponds, or irrigation systems along water courses. Fertilisers and improved tef varieties are other examples of strategies that are more needed today than in the 1960´s when there was more land available per household. The study sites in this thesis, Kete and Wenchi are located in a favourable agro-ecological zone regarding rainfall and temperature. This is probably the reason why people settled here in the first place and also a reason why areas like this has had an increase in population. The nuances of the constraints that farmers in rural Ethiopia are facing do not only vary within the country; it also shows large differences within a kebelle, or between neighbouring valleys. Farmers´ constraints show that it is a very complex situation that is not static.

The overall conclusions that can be drawn from the study are that:

- Regional differences of rainfall change have taken place during the past 30 years in the Ethiopian highlands. The main differences are related to the starting date of the two rainy seasons, the amount of rainfall during the rainy seasons and the variability of rainfall.
- A decline in the *Belg* rainfall and an increase of the *Kiremt* rainfall has occurred during the time period 1978-2007.
- Tef cultivation during the *Belg* season shows that farmers had a potential yield every second year during the time period 1963-2003.
- The soils are generally good, but a very low organic content especially in Tehuledere may indicate intensive use of farm land. Few farmers have the possibility to keep land in fallow which prevents the build-up of organic matter in the soil. The comparatively high organic content in enset cultivations suggests that this cropping strategy has a significant positive effect on the soils as compared to, for example, tef cultivation.
- The change in rainfall variability though time may differ significantly even in a very local scale. Places such as Hayk and Combolcha only 30 km apart rainfall has experienced completely different changes during the *Belg* season, which means that tef cultivation during the *Belg* season is more or less impossible in Combolcha.
- A higher pressure on land due to more houses established and also the expansion of Hayk town has created a situation with a decline in farm land.

8. Future research

The results in this thesis can help and improve the understanding of farmers living conditions in the highlands of Ethiopia. The changes of the natural conditions such as rainfall, the status of soil parameters and changes in land use over time are important assets for the farmers. The rainfall model for tef cultivation has provided an opportunity to analyse the impact of rainfall change on the tef cultivation.

During the work with this thesis, several important aspects have emerged. To further improve the understanding and importance of small scale land use changes and the driving forces behind this change, detailed mapping and in-depth interviews with the farmers would be a step further to understand the problems the rural people in Ethiopia are facing. As a suggestion the input of fertilisers, the size of harvest, the knowledge of sowing time (*tef*) and harvest time etc. at an administrative level corresponding to a *got* would be preferable.

Large scale land use changes in South Wollo would also be of interest in order to understand local differences due to for example different agro-ecological zones and vicinity to big towns.

The intensification of farm land documented in Kete kebelle together with the low content of organic matter, which has not previously been documented in the area would need recommendations by local authorities and extension officers to highlight the importance of increasing the organic matter which plays a vital role for soil fertility (Solomon et al, 2002). This exchange of knowledge would enhance the possibilities to find a solution to maintain or improve the crop yield for the farmers. Considering the fact that the other soil parameters were adequate for crop production, the improvement of soil organic matter is important to highlight at a local level. Researchers, farmers and authorities can hopefully jointly make an attempt to improve that situation.

The significant decline of *Belg* rainfall after 1996 is most important, and the findings of the *Belg* decline throughout Ethiopia emphasises the importance of food security. The impact this will have on farmers' potential food production and the increase in urban population that is in need of inexpensive food will be challenged by this change in rainfall. To test the rainfall model under different natural conditions such as different soil types, different agro-ecological zones, different positions in the landscape among other natural conditions parameters, would be rewarding and hopefully of gain for the farmers that need to optimize yield on every square meter of their precious farm land. The later start of the *Belg* season across the highland area of Aleltu to Hayk opens up for further analysis of the changes of the *Belg* and *Kiremt* rainfall seasons across the Ethiopian highlands and furthermore, the impact this has on cropping strategies among the farmers.

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References

Abebe M (2006) The onset, Cessation and Dry Spells of the Small rainy Season (Belg) of Ethiopia. Addis Ababa

Alemu G, Bayu W (2005) Effects of Farmyard Manure and Combined N and P Fertilizer on Sorghum and Soil Characteristics in Northeastern Ethiopia. Journal of Sustainable Agriculture 26 (2):23-41. doi:10.1300/J064v26n02_04

Amsalu A, Stroosnijder L, Graaff J (2007) Long-term dynamics in land resource use and the driving forces in the Beressa watershed, highlands of Ethiopia. Journal of Environmental Management 83 (4):448-459

Asmamaw L, Mohammed A, Lulseged T (2011) Land use/cover dynamics and their effects in the Gerado catchment, northeastern Ethiopia. International Journal of Environmental Studies 68 (6):883-900

Asrat P, Belay K, Hamito D (2004) Determinants of farmers' willingness to pay for soil conservation practices in the southeastern highlands of Ethiopia. Land Degradation & Development 15 (4):423-438. doi:10.1002/ldr.623

Atlas of Rural Ethiopian Economy (2006). International Food Policy Research Institute and the central statistical agency Addis Ababa, Ethiopia, Washington

Aune JB, Tera M, Bussa T, Gugsa FA, Ayele AA (2001) The ox ploughing system in Ethiopia can it be sustained? Outlook on Agriculture 30 (4):275-280

Awulachew SB, Ayana M (2011) Performance of irrigation: An assessment at different scales in Ethiopia. Experimental Agriculture 47:57

Bantider A, Hurni H, Zeleke G (2011) Responses of rural households to the impacts of population and land-use changes along the Eastern Escarpment of Wello, Ethiopia. Norsk Geografisk Tidsskrift - Norwegian Journal of Geography 65 (1):42-53. doi:10.1080/00291951.2010.549954

Bevan P, Pankhurst A (1996) A social analysis of fifteen rural economies in Ethiopia. Overseas Development Administration, UK

Bewket W Rainfall variability and crop production in Ethiopia Case study in the Amhara region. In: The 16th International Conference of Ethiopian Studies,, Trondheim, 2009.

Bewket W, Abebe S (2013a) Land-use and land-cover change and its environmental implications in a tropical highland watershed, Ethiopia. International Journal of Environmental Studies 70 (1):126-139. doi:10.1080/00207233.2012.755765
Bewket W, Abebe S (2013b) Land-use and land-cover change and its environmental implications in a tropical highland watershed, Ethiopia. International Journal of Environmental Studies 70:1 126-139. doi:http://dx.doi.org/10.1080/00207233.2012.755765
Bewket W, Conway D (2007) A note on the temporal and spatial variability of rainfall in the drought-prone Amhara region of Ethiopia. International Journal of Climatology 27 (11):1467-1477. doi:10.1002/joc.1481
Bewket W, Sterk G (2002) Farmers' participation in soil and water conservation activities in the Chemoga Watershed, Blue Nile basin, Ethiopia. Land Degradation & Development 13 (3):189-200. doi:10.1002/ldr.492
Bezabih M, Kohlin G, Mannberg A (2011) Trust, tenure insecurity, and land certification in rural Ethiopia. The Journal of Socio-Economics 40 (6):833-843. doi:http://dx.doi.org/10.1016/j.socec.2011.08.015
Camberlain P (1997) Rainfall Anomalies in the Source Region of the Nile and Their Connection with the Indian Summer Monsoon. Journal of Climate 10:1380-1392
Carney D (1998) Sustainable Rural Livelihoods, what contribution can we make? Russell Press Ltd, Nottingham
CIA (2014). https://www.cia.gov/library/publications/the-world-factbook/geos/et.html.
Conway D (2000) The Climate and Hydrology of the Upper Blue Nile River. The Geographical Journal 166 (1). doi:10.1111/j.1475-4959.2000.tb00006.x
Conway D, Mould C, Bewket W (2004) Over one century of rainfall and temperature observations in Addis Ababa, Ethiopia. International Journal of Climatology 24 (1):77-91. doi:10.1002/joc.989
Coorbeels M, Shiferaw, A. and M. Haile (2000) Farmers knowledge of Soil Fertility and Local Management strategies in Tigray, Ethiopia. Managing Africa´s Soils 10
Critchley W (2000) Groundtruthing : new perspectives on soil erosion and conservation in the tropics. s.n.], [Netherlands
Critchley W, Gowing J (2012) Water Harvesting in Sub-Saharan Africa. Routledge, Abingdon
CSA (2007) Population and Housing Census Report-Country - 2007. http://www.csa.gov.et/index.php/2013-02-20-14-51-51/2013-04-01-11-53-00/census-2007. Accessed 24/5/2013 2013
CSA (2013). http://www.csa.gov.et. Accessed 17/12/2013 2013
CSA.gov.et (2014). http://www.csa.gov.et.
Degefu W (1987) Some aspects of meteorolggical drought in Ethiopia. In: Glantz MH (ed) Drought and hunger in Africa. Press Syndicate of the University of Cambridge, Cambridge, p 457
Dessie G (2007) Forest decline in South Central Ethiopia. PhD, Stockholm, Stockholm
Dessie G (2013) Is khat a social ill? African Studies Centre Leiden, The Netherlands
Diro G, Grimes D, Black E (2011) Large Scale Features Affecting Ethiopian Rainfall. In: Williams CJR, R KD (eds) African Climate and Climate Change: Physical, Social and Political Perspectives, vol 43. Advances in Global Change Research. pp 13-50. doi:10.1007/978-90-481-3842-5_2
DRMFSS (2013) Disaster Risk Management and Food Security Sector (DRMFSS), Ministry of Agriculture (MoA). http://www.dppc.gov.et. Accessed 31/5/2013
ESA.UN (2013a). http://esa.un.org/unpd/wpp/unpp/p2k0data.as. Accessed 27/2/2013 2013
ESA.UN (2013b) World Urbanization Prospects. http://esa.un.org/unup/. Accessed 24/5/2013
EthioGIS (1999) EthioGIS.
Ethiopian Mapping Authority (1993) Ethiopia 1:50 000 ETH 41139 D1 1 EMA 1993. Addis Abeba, Ethiopia
Evangelista P, Young N, Burnett J (2013) How will climate change spatially affect agriculture production in Ethiopia? Case studies of important cereal crops. Climatic Change:1-19
FAO (2013a). http://faostat.fao.org/site/550/DesktopDefault.aspx?PageID=550#ancor.

FAO (2013b). http://faostat.fao.org/site/291/default.aspx. Accessed 17/12/2013 2013
FEWS (2013). www.fews.net.
Gebregziabher S, Mouazen A, Van Brussel H, Ramon H, Nyssen J, Verplancke H, Behailu M, Deckers J, De Baerdemaeker J (2006) Animal drawn tillage, the Ethiopian ard plough, maresha: A review. Soil and Tillage Research 89 (2):129-143. doi:10.1016/j.still.2005.08.010
Gebrernichael D, Nyssen J, Poesen J, Deckers J, Haile M, Govers G, Moeyersons J (2005) Effectiveness of stone bunds in controlling soil erosion on cropland in the Tigray Highlands, northern Ethiopia. Soil Use and Management 21 (3):287-297. doi:10.1111/j.1475-2743.2005.tb00401.x
Getachew HE, Melesse AM (2012) The Impact of Land Use Change on the Hydrology of the Angereb Watershed, Ethiopia. International Journal of Water Sciences 1:4:1-7
Haile H, Alemu Z, Kudhlande G (2005) Causes of Household Food Insecurity in Koredejaja Pleasant Association, Oromiza Zone. Ethiopia, Working Paper, Department of Agricultural Economics, University of Free State,
Humanatarian practice network (2004). http://www.odihpn.org/.
Hurni H (1995) Soil Conservation in Ethiopia. Watershed Development and Land Use Department, Ministry of Natural resources Development and Environmental Protection Switzerland
Hurni H Precious Earth: From Soil and Water Conservation to Sustainable Land Management. In: International Soil Conservation Organisation (ISCO) and Centre for Development and Environment (CDE), Berne, 1996. p 89
Jayne TS, Yamano T, Weber MT, Tschirley D, Benfica R, Chapoto A, Zulu B (2003) Smallholder income and land distribution in Africa: implications for poverty reduction strategies. Food Policy 28 (3):253-275. doi:10.1016/s0306-9192(03)00046-0
Jones A, Breuning-Madsen H, Brossard M, Dampha A, Deckers J, Dewitte O, Gallali T, Hallett S, Jones R, Kilasara M (2013) Soil atlas of Africa.
Marcus HG (2002) A History of Ethiopia. Univ. of California Press, cop., Berkeley, California
Meze-Hausken E (2004) Contrasting climate variability and meteorological drought with perceived drought and climate change in northern Ethiopia. Climate Research 27:19-31
Moges A, Holden NM (2008) Estimating the rate and consequences of gully development, a case study of umbulo catchment in Southern Ethiopia. Land Degradation & Development 19 (5):574-586. doi:10.1002/ldr.871
Nicholson SE (2000) The nature of rainfall variability over Africa on time scales of decades to millenia. Global and Planetary Change 26 137–158
NMSA (1996) Climatic & Agroclimatic resources of Ethiopia. vol 1. Addis Ababa
Nyssen J, Poesen J, Moeyersons J, Deckers J, Haile M, Lang A (2004) Human impact on the environment in the Ethiopian and Eritrean highlands—a state of the art. Earth-Science Reviews 64 (3-4):273-320. doi:10.1016/s0012-8252(03)00078-3
Nässen K (2009) Mark är som barn. Genus, fattigdom, och försörjning i Södra Wollo, Etiopien. University of Gothenburg, Göteborg
Omiti J, Parton K, Sinden J, Ehui S (1999) Monitoring changes in land-use practices following agrarian de-collectivisation in Ethiopia. Agriculture, ecosystems & environment 72 (2):111-118
Ovuka M (2000) Effects of soil erosion on nutrient status and soil productivity in the central highlands of Kenya. Phd, University of Gothenburg, Göteborg
Pan G, Smith P, Pan W (2009) The role of soil organic matter in maintaining the productivity and yield stability of cereals in China. Agriculture, Ecosystems & Environment 129 (1-3):344-348. doi:10.1016/j.agee.2008.10.008
Rosell S (2011) Regional perspective on rainfall change and cereal production in North Shewa & South Wollo, Ethiopia 1978-2007.pdf. Applied Geography 31:329-338
Rosell S, Holmer B (2007) Rainfall change and its implications for Belg harvest in South Wollo, Ethiopia. Geografiska Annaler: Series A, Physical Geography 89 (4):287-299

Rosell S, Holmer B (2014) Erratic rainfall and its consequences for cultivation in two adjacent areas in South Wollo, Ethiopia. Norsk Geografisk Tidsskrift - Norwegian Journal of Geography

Rosell S, Olvmo M (2014) An Analysis of Soil Productivity Parameters and Livelihoods in West Shewa and South Wollo, Ethiopia. Scottish Geographical Journal Volume 130 (1):16. doi:10.1080/14702541.2013.820027

Scoones I (1998) Sustainable rural livelihoods: a framework for analysis. IDS working paper, Vol. 72, . Brighton IDS

Seleshi Y, Camberlin P (2005) Recent changes in dry spell and extreme rainfall events in Ethiopia. Theoretical and Applied Climatology 83 (1-4):181-191. doi:10.1007/s00704-005-0134-3

Seleshi Y, Zanke U (2004) Recent changes in rainfall and rainy days in Ethiopia. International Journal of Climatology 24 (8):973-983. doi:10.1002/joc.1052

Shanko D, Camberlin P (1998) The effects of the Southwest Indian Ocean tropical cyclones on Ethiopian drought. International Journal of Climatology 18 (12):1373-1388. doi:10.1002/(SICI)1097-0088(1998100)18:12<1373::AID-JOC313>3.0.CO;2-K

Simelton E (2007) Climate and Human Impacts on Wheat Production and Land Use in the Loess Plateau Region, China. Phd, University of Gothenburg, Gothenburg

Smithson P, Addison, K., & Atkonson, K. (2008) Fundamentals of the Physical Environment. In., 4th edn. Routledge, London and New York,

Stock R (2012) Africa South of the Sahara, Third Edition: A Geographical Interpretation. Guilford Publications,

Stocking M (1984) Erosion and Soil Productivity A review.

Tegene B (2002) Land-cover/land-use changes in the Derekolli Catchment of

the south Welo Zone of Amhare Region, Ethiopia. . Eastern African Social Science Research Review 18(1):1–20.

Tekle K, Hedlund L (2000) Land cover changes between 1958 and 1986 in Kalu District, southern Wello, Ethiopia. Mountain research and development 20 (1):42-51

Thorntwaite CW (1948) An approach toward a rationale classification of climate. Geographical Revew 38:55-94

Tisdale SL, Nelson, W.L., Beaton, J.D. and J.L., Havlin (1993) Soil Fertility and Fertilizers. 5th edn. Prentice Hall Inc.,

Tschopp R, Aseffa A, Schelling E, Zinsstag J (2010) Farmers' Perceptions of Livestock, Agriculture, and Natural Resources in the Rural Ethiopian Highlands. Mountain Research and Development 30 (4):381-390. doi:10.1659/mrd-journal-d-09-00072.1

Tsegaye A, E A, G SY (2012) Impact of Land Certification on Sustainable Land Resource Management in Dryland Areas of Eastern Amhara Region, Ethiopia. Journal of Agricultural Science Vol. 4 (12):8

Ubink J, Hoekema A, Assies W (2009) Legalising land rights. Law Governance and Development Research. Leiden

UN.org (2013). http://www.un.org/en/development/desa/population/theme/trends/index.shtml. Accessed 5/5/2013 2013

USAID (2009) Ethiopia GIS Shape-files.

Viste E, Korecha D, Sorteberg A (2012) Recent drought and precipitation tendencies in Ethiopia. Theoretical and Applied Climatology. doi:DOI 10.1007/s00704-012-0746-3

WorldBank.org (2013). http://databank.worldbank.org/ddp/home.do?Step=3&id=4. Accessed 6/3/2013 2013

Worldclimate (2013) Worldclimate. http://www.worldclimate.com/cgi-bin/place.pl?pla=combolcha. Accessed 17/12/2013 2013