Towards integrated watershed management in highland Ethiopia: the Chemoga watershed case study

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Wageningen, April 2003

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Chapter 1

Introduction

Introduction

Ethiopia is a large country (>1.1M km^2) that is endowed with very diverse physiographic and climatic conditions which have made possible the presence of diverse faunal and floral resources (FDRE, 1997). Presently, more than 64 million people, growing at a rate of ~2.7% per annum, inhabit the country (CSA, 1998; World Bank, 2002). The foundation of the national economy is agriculture. Smallholder farm household production system, where livestock plays a key role, is predominant which is producing over 90% of the total agricultural output (Shiferaw and Holden, 1999). Over the past three decades, Ethiopia has been unable to feed her population. Growth in food production lingered behind the population growth (Mulat, 1999). This means that per capita food availability has been falling and food insecurity and poverty worsening. The country has become a major food aid recipient in Africa (Clay et al., 1999). Resource degradation is identified to be one of the major reasons for this distressing trend in the food production and economic growth (Hurni, 1993; Sutcliffe, 1993; Kebrom, 1999; Shiferaw and Holden, 1999; Girma, 2001).

The degradation of resources is caused by the heavy pressure from the human and livestock populations, coupled with many other physical, socioeconomic and political factors (Sonneveld, 2002). Much of the pressure is found in the highlands above 1500m (~45% of the country's total area) (FAO, 1986). These highlands, which are characterised by favourable environmental conditions, have been settled for millennia and agriculture has a matching history (McCann, 1995). According to El-Swaify and Hurni (1996), the Ethiopian highlands constitute one of the most degraded lands in Africa. The most pressing forms of resource degradation are destruction of natural vegetative covers and soil erosion by water.

Soil erosion by water is by far the biggest land degradation problem (FAO, 1986; Hurni, 1993). As estimates from a national-level study indicate, average soil removal all over the country is about 2 billion tyr^{-1} (FAO, 1986). The highest rate of soil loss occurs from cultivated fields, which is estimated at 42 $tha^{-1}yr^{-1}$ on average (Hurni, 1993). Assuming an average soil depth of 60cm, Hurni (1993) predicted that most of the area of cultivated slopes in the highlands would be entirely stripped of the soil mantle within 150 years. In economic terms, soil erosion is estimated to have cost Ethiopia 619.2 million Birr by the year 1990 (Sutcliffe, 1993) (2.07 Birr ~ 1.00 USD by that time). Referring to this massive loss of the soil resource from the highlands of Ethiopia and its transport to the neighbouring downstream countries, specifically Egypt and the Sudan, some researchers use a cynical metaphor- 'the country's largest export' (Markos, 1997; Omiti et al., 1999). These negative trends in the food production and status of natural resources suggest that efforts that integrate conservation and development measures are crucially needed in Ethiopia.

Past experience and the need for a new approach to resource conservation

Resource degradation has been recognised to be a serious problem in highland Ethiopia since the early 1970s, subsequent to the disastrous drought and famine of the time. Considerable efforts have been made since then to rehabilitate degraded environments and stop further degradation. The emphasis has been on construction of mechanical soil and water conservation (SWC) measures in cultivated fields and the afforestation of hillsides, which are common property resources. The largest conservation activities in the country are those implemented during the 1970s and 1980s (during the *derg* regime), for which the farmers were mobilized at the national level for campaign works. The international donor community made significant contributions to those conservation efforts by supplying food grains and edible oil that were used as food-for-work payments for the 'participating' farmers. The national effort, combined with the huge assistance from the international aid agencies, resulted in achievements that were described as 'impressive' (Wood, 1990; Scoones et al., 1996). However, those achievements were later evaluated as only quantitative with minimal desirable outcomes and ineffective and unsustainable (Azene, 1997; Yeraswork, 2000). The whole effort was, therefore, eminently a failure. Several factors have been identified as reasons for the failure. The most important of all is said to be the top-down approach pursued in the planning and implementation processes (Stahl, 1990; Azene, 1997; Yeraswork, 2000).

The involvement of the farmers in those conservation activities was limited to labour contribution, which was induced either by coercion or the food-for-work payments. The underlying faulty assumption was that the externally introduced conservation measures would halt the degradation problem and lead to sustainable land use. The local farmers were virtually considered ignorant of land management and were not allowed to comment on the introduced conservation measures, which were alien and foreign to them. On their part, the farmers were dissatisfied because the conservation measures were neither addressing their needs and priorities nor fitting to their farming system circumstances. After the food-for-work payments were discontinued and the coercive force withdrew with the fall of the *derg* regime, the conservation measures failed to be worthy of maintaining to the farmers. Instead, the farmers demolished most of the SWC structures that were constructed in their cultivated fields and resorted to their traditional practices of land use.

Since the 1990s, resource conservation activities, mainly SWC works in cultivated fields, have been undertaken as part of the agricultural extension package of the present government. However, the practice has remained delivery-oriented in which the farmers are forced to implement conservation measures designed for them by technical experts. The farmers are not involved in the processes of selection and planning of the conservation measures. As shown by experiences of the past, these top-down conservation practices cannot be expected to be effective and sustainable. The result is that resource degradation remains perilous to the national economy. It needs to be tackled through new conservation strategies, approaches and technologies.

Given the diversity in the physical and socioeconomic environments and the spatial variations in the type and severity of resource degradation in Ethiopia, any effort at conservation needs to be site-specific. Designing realistic and acceptable conservation techniques and identifying promising approaches for intervention require a rigorous understanding of the processes, extent and rate of resource degradation and the socioeconomic and institutional circumstances at the local-level. The physically appropriate spatial units for research on resource conservation issues are watersheds (Gregersen et al., 1996; Brooks et al., 1997). The watershed context provides the natural framework for investigation into the complex and reciprocal linkage among land use, soil and water resources, and the interdependence of people in their resource-use practices. Because of this physical significance, watersheds are also considered to be the logical spatial constructs for the sustainable and integrated management of the resources with the direct involvement of local populations and the practice is what is popularly known as integrated watershed management (Brooks et al., 1997; Sharma, 1999; Rhoades, 2000).

The aim of integrated watershed management (IWM) is to achieve sustainable resource management and sustainable rural livelihoods concurrently with the full involvement of the people affected (Rhoades, 2000). There are logical reasons from the biophysical and the social perspectives that justify the need to combine physical properties of watersheds with the involvement of local populations for resource conservation. From the biophysical perspective, watersheds constitute the appropriate physical units for the sustainable management of resources in an integrated manner. IWM takes into consideration the interactions between land use, soil and water resources as well as upstream and downstream linkages. From the social perspective, the genuine involvement of the local populations is imperative if locally relevant, acceptable and sustainable resource conservation and development measures are to be designed and implemented. At the present, the IWM approach is being pursued in many countries of the world- in Asia, Latin America, Africa, Australia and USA (Rhoades, 2000). The emerging evidences from experiences in many of these countries show that the IWM approach generally leads to effective resource conservation and improved livelihoods (Sharma, 1997; Hinchcliff et al., 1999). In view of these success stories and its logically convincing significance, the need for and possibilities of implementing the IWM approach in the Ethiopian highlands merits investigations. No attempt has ever been made to introduce this approach into Ethiopia.

Objectives of the study

The main objective of this study was to explore the need for and possibilities of implementing the IWM approach for resource conservation in the Ethiopian highlands. A typical highland watershed was selected for the research. The following specific objectives were defined: (i) to evaluate the extent, rate and processes of resource degradation, (ii) to describe the existing socioeconomic conditions, resource-use and management practices, and (iii) to identify the requirements for the practical implementation of IWM in highland Ethiopia.

The study site: the Chemoga watershed

The Chemoga watershed lies within $10^0$18'N to $10^0$39'N and $37^0$44'E to $37^0$53'E. In administrative terms, it is located in Gozamen woreda (district), East Gojjam zone, Amhara Regional State (Fig. 1). The watershed is located at some 300km northwest of Addis Ababa, and forms part of the northwestern highlands of Ethiopia. It is characterised by diverse topographic conditions. The elevation ranges from 2420m to nearly 4000m. A mountainous and highly dissected terrain with steep slopes characterises the upstream part; and an undulating topography and gentle slopes characterise the downstream part. The soils that cover much of the total area of the watershed can be classified into three broad types on the basis of their colour: dark brown, reddish and grayish (gray to dark). The dark brown soils are at high altitudes with a temperate- and alpine-like climate. The reddish soils occur on nearly level to gently undulating land that is well drained and largely occupy the midstream and downstream parts of the watershed. The grayish (gray to dark) soils occur in the flood plains in the downstream reach of the watershed, where sedimentation occurs every wet season.

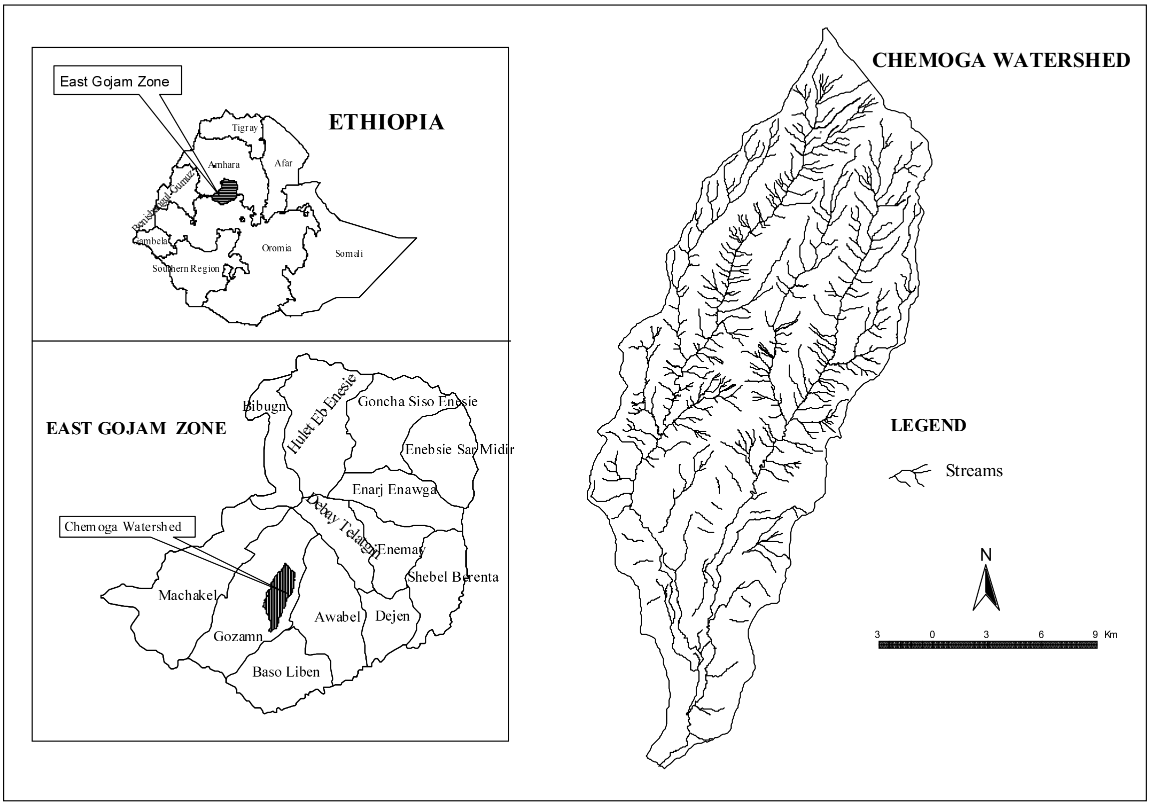

Figure1. Location map of the study area

The climatic condition is generally humid. As measured at Debre-Markos ($10^0$20'N, $37^0$40'E and elevation 2411m), the mean annual temperature is 14.5^{0}C and the average annual total rainfall is 1300 mm. More than 75% of the total rain falls in the four months of June to September (*kiremt* season); and less than 5% of the total occurs during the dry months of November to February (*bega* season). Since the watershed lies at a higher elevation than Debre-Markos, temperatures must be lower and rainfall probably higher than these values. Average annual total potential evapotranspiration (PET), as estimated with the Thornthwaite's method (Thornthwaite, 1948), is 855.7 mm. The monthly rainfall exceeds the calculated PET only in the months of June to October (Fig. 2). The uneven distribution of the rainfall gives rise to a serious shortage of water during the dry season in some parts of the watershed.

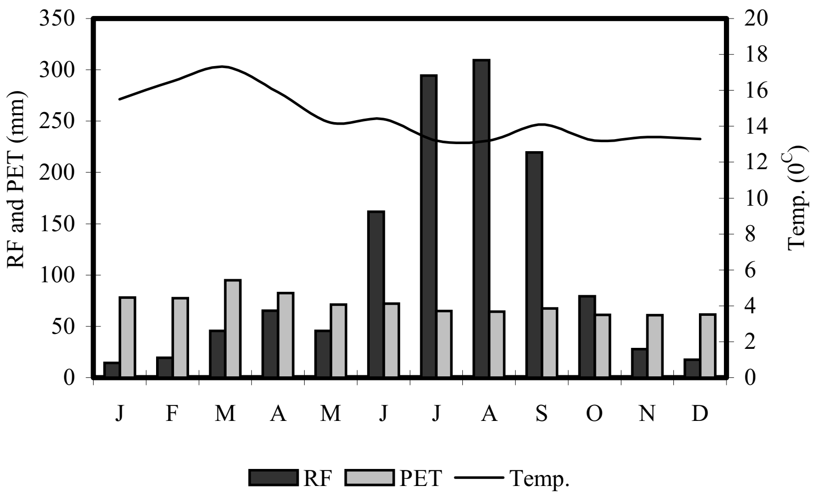

Figure 2. Mean monthly rainfall (RF), potential evapotranspiration (PET) and temperature (Temp.).

With the total area of 364 km^2, the Chemoga watershed is inhabited by a total population of ~40,768, according to the rural population density (112 persons/km^2) estimation for the Gozamen woreda (Gozamen Woreda Office of Agriculture, 2001). This population density is slightly higher than the average for the Amhara Regional State (99.6 persons/km^2) and much higher than the national average (49.3 persons/km^2) (NOP, 1999). The farming system is a typical mixed crop-livestock system that is carried on a subsistence scale. Land and livestock are therefore the most important assets of the people, with which they lead a sedentary life. Livestock provide the draught power and household members the labour that is needed for the farming operation. A variety of crops are produced by a household because of the strong orientation towards self-sufficiency. Barley (*Hordeum vulgare*), wheat (*Triticum vulgare*), oats (*Avena sativa*), horse beans (*Vicia faba*), potato (*Solanum tuberosum*) and onion (*Allium cepa*) are grown in the upstream part of the watershed; and *tef* (*Eragrostis tef*) is additionally cultivated in the downstream part. Crop production is the major source of income to the households. Incomes from off-farm employment, where the definition of off-farm employment included all activities outside of one's own farm: working on another farmer's farm, petty trading, weaving, carpentry, smithing and pottery, are scanty (Woldeamlak, 2001).

The rationales for selection of the Chemoga watershed as the site for this study were multiple. Firstly, it is typical of the northwestern highlands of the country in terms of the various environmental attributes such as topography, soils, climate, and the socioeconomic environment. Secondly, the watershed is part of the highlands that are known to be surplus producing regions, but presently threatened by resource degradation and impending food insecurity (Gete, 2000). Thirdly, some necessary data were readily available. Besides, no study has been carried out on the issue of resource degradation and management in this particular watershed. The fact that the study is site-specific is believed to make it a valuable contribution to the much-needed but very scarce local-level understanding on the problem of resource degradation in the country. As noted above, the diverse environmental conditions in the country demand site-specific conservation planning, which requires site-specific investigations into the problem. On the other hand, even though the empirical research findings are revealing the reality in the case study site, the facts, analyses and conclusions generally unveil the conditions in much of highland Ethiopia. Thus, recommendations given on necessary measures that ought to be taken to promote sustainable resource use have a wider relevance.

Study outline

This thesis is the result of a multiperspective and multiscale investigation on the extent, rate and processes of resource degradation, and the existing resource-use and management practices in the Chemoga watershed. It has two parts. In part I the analyses of resource degradation are presented (chapters 2 through 5); and in part II the socioeconomic conditions, resource-use and management practices in the area are presented (chapters 6 through 9). Several themes were covered by the study. Temporal changes in land cover/use during the past four decades were evaluated by using remotely sensed images (aerial photographs and a satellite image) of the area, and the results are presented in chapter 2. The causes and environmental implications of the observed dynamics in land cover are also discussed in the same chapter. The effect of the land use system and its pattern of change over time on the soil resource, specifically on soil physical and chemical properties were appraised by employing an 'inferential approach', by which soil samples were collected from the different land cover/use types and analysed for differences in their physico-chemical properties (chapter 3). The need for site-specific approaches for soil management is underscored in this chapter.

As is well known, changes in land cover/use and the state of the soil resource affect the hydrological regime of watersheds. To distinguish any such effects, hydrometric records of the watershed, which were available for the period of the past four decades, were analysed in daily, monthly and annual time-steps, and the results are reported in chapter 4. A field-scale soil erosion assessment was also carried out to examine the severity of the erosion problem in the cultivated fields of the area (chapter 5). This was done by field surveying of soil losses due to rill erosion.

The status and dynamics of resources are generally reflections of the local peoples' resource-use and management practices. The local people are entirely dependent on natural resources for their livelihood. In chapter 6, the socioeconomic circumstances of the farm households and the scarcity and degradation of the resource base are described from the farmers' perspective. As a response to the growing scarcity of wood for fuel and other uses, the households planted trees in privately operated lands (chapter 7). Resource degradation is acknowledged to be a problem in the area and government-sponsored conservation efforts, which focused on SWC, are underway. The extent of the farmers' involvement in these SWC activities is examined in chapter 8. In chapter 9, IWM approach is discussed as an option for a sustainable resource conservation and development. The arguments are derived from findings of the component topics (chapters 2 through 8). Chapter 10 presents a summary of the major conclusions of the study.

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Chapter 2

Land cover dynamics since the 1950s in the Chemoga watershed, Blue Nile basin, Ethiopia

Woldeamlak Bewket

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Land cover dynamics since the 1950s in the Chemoga watershed, Blue Nile basin, Ethiopia

Abstract

This study evaluated changes in land cover in the Chemoga watershed, headwater to the Blue Nile. Two sets of aerial photographs (1957 and 1982) and a multispectral Spot image (1998) were used as inputs to produce three GIS-based land cover maps of the area. The results show that during the last forty-one years, forest cover increased at a rate of about 11 ha per annum in the 36,400 ha watershed. Woodlands and shrublands decreased between 1957 and 1982 but increased between 1982 and 1998, approximately to their previous levels. Farmland and settled areas gained from the other cover types (13% increase) in the first period but lost around 586 ha (2% decrease) in the second. Grassland and degraded land decreased accounting for 4.8% of the total area of the watershed in 1982 and 3.5% in 1998, as against 9.6% in 1957. Riverine trees suffered the greatest destruction, shrinking by 79% over the four decades; much of this decline was due to cultivation. Marshlands increased in the first period and decreased in the second. A new pond emerged amid the marshlands between 1982 and 1998. Population growth and the associated demand for land and trees was the major driving force behind the changes. This study shows that the deforestation trend was reduced and even partly reversed in the area. This trend ought to be encouraged through appropriate interventions – in particular by promoting planting of local tree species rather than eucalypts at the household level – to increase not only economic but also ecological benefits. Indeed, the current state of land cover and its dynamics have environmental implications at the local scale and beyond. Hence, environmental management for sustainable development requires interregional and international cooperation.

Key words: land cover changes; remote sensing; afforestation; Ethiopia

Assessing land cover dynamics

Land cover dynamics – particularly deforestation – has become a global concern, as its implications for human livelihood systems are immense. It is one of the major topics in current global change studies (e.g. climate change, alteration of biogeochemical cycles) jointly initiated in 1996 by the International Geosphere–Biosphere Program (IGBP) and the International Human Dimensions Program on Global Environmental Change (IHDP) (IGU, 1998). In Ethiopia, accelerated deforestation has been taking place since the beginning of the 20th century (EFAP, 1993). Although forests were thought to have covered nearly 40% of the country's total area at the beginning of the 20th century (Breitenbach, 1961; EFAP, 1993), forest cover today is estimated at only 2 to 3% (EFAP, 1993). The rate of deforestation is estimated to be between 150,000 and 200,000 ha per annum (EFAP, 1993). But, estimates of original forest cover and deforestation rates differ greatly from one source to another because information is derived mostly from indirect sources (e.g. travelers' accounts) and less often, if at all, from quantitative studies where forest cover is measured at different time intervals. But the general consensus is that the scale of clearance in Ethiopia has been massive.

Large-scale destruction of forest resources is not the only change that has taken place at the national level. Major land cover changes have also occurred at the local level for all land types. For instance, Solomon (1994) reported rotational land cover/ use involving cultivation and vegetation (forest and bush) between 1957 and 1982 in the Metu area, southwestern Ethiopia. A significant increase in cultivated land at the expense of forestland was found to have occurred between 1957 and 1995 in the Dembecha area, northwestern Ethiopia (Gete, 2000). Kebrom and Hedlund (2000) reported increases in open areas and settlements at the expense of shrublands and forests between 1958 and 1986 in the Kalu area, northcentral Ethiopia. On the other hand, increases in forestland and cultivation land at the expense of grazing land were detected in Sebat-bet Guraghe, southcentral Ethiopia (Muluneh, 1994) between 1957 and 1994.

Such local-level dynamics play a significant role in determining the health of an ecosystem at the micro-level. Studies of the magnitude, rates, patterns, causes and biophysical and socioeconomic implications of land cover dynamics at the local level can help design more effective land management strategies and policies. But investigations of land cover dynamics at this level are rare in Ethiopia, a deficiency that this study tries to correct in the case of the Chemoga watershed. The specific objectives are to evaluate changes in land cover over a period of time on the one hand and describe the possible causes and environmental implications of these changes on the other.

The study area: Chemoga watershed

The Chemoga watershed lies between 10^{0}18'N and 10^{0}39'N and 37^{0}44'E and 37^{0}53'E. In administrative terms, it is located in Gozamen woreda (district), East Gojjam zone, Amhara Regional State (Fig 1). It covers an area of 364 km^2 and has a population of about 40,768, according to the rural population density (112 persons/km^2) estimation for the Gozamen woreda (Gozamen Woreda Office of Agriculture, 2001). The Chemoga watershed is one of the headstreams of the Blue Nile. The Blue Nile is the largest tributary of the Nile, contributing around 86% of its total annual discharge (Conway, 1997). In recent years, the amount of water carried downstream by the Blue Nile declined significantly (Mengistu, 1997), whereas the mass of sediments transported increased (El-Swaify and Hurni, 1996), because of environmental degradation in the highlands of Ethiopia. The Chemoga watershed is part of this degraded and degrading basin; it is representative of the conditions in large parts of the temperate and alpine climatic and agro-ecological belts (locally known as *dega* and *wurch*) in the northwestern highlands. As measured at Debre-Markos (10^{0}20'N, 37^{0}40'E and elevation 2411 m), the mean annual temperature is 14.5^{0}C, ranging between 13.2^{0}C in July and August and 17.3^{0}C in March. The average annual rainfall is 1300 mm; more than 75% of the total precipitation occurs in the four months from June to September. Because the Chemoga watershed lies at a higher elevation than does Debre-Markos (between 2420 and 4000 m), temperatures are significantly lower and rainfall is probably higher than these values. Average annual total potential evapotranspiration (PET), as estimated with the Thornthwaite (1948) method, is 855.7 mm, with very low monthly variation.

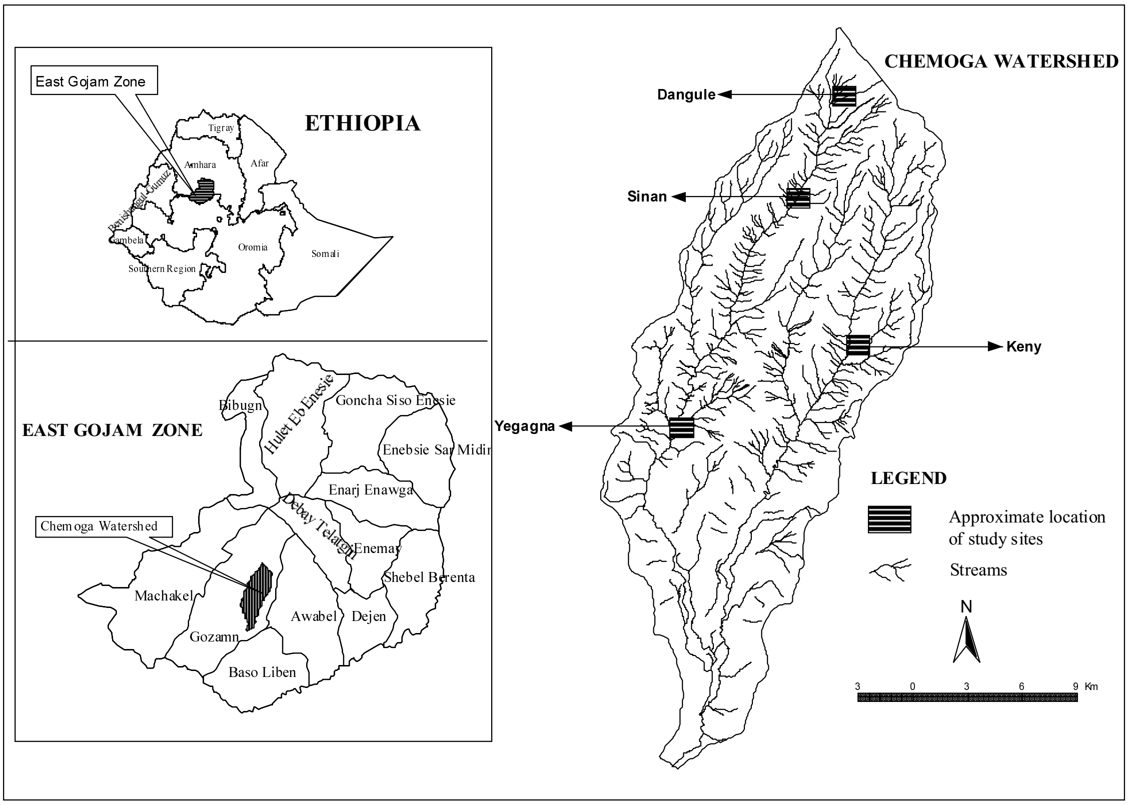

Figure 2. Location map of Chemoga watershed

Materials and methods

The materials used to create the spatial database needed for this study were two sets of panchromatic aerial photographs taken in 1957 (December) and 1982 (January), and a multispectral (three-band) Spot image dated December 1998. Both sets of photographs have base scales of about 1:50,000 and were obtained from the Ethiopian Mapping Authority (EMA). Twenty photographs from 1957 and 19 photographs from 1982 covered the watershed studied. The use of the Spot image was necessary because recent aerial photographs were not available. On the other hand, the photographs were the only sources of information for the period predating the launch of the Spot satellites. Hence, for this study it was necessary to combine aerial photographs and a satellite picture.

The establishment of the databases involved: (1) scanning the aerial photographs with a 600 dots per inch scanner, (2) geo-referencing the photo mosaics according to the Universal Transverse Mercator (UTM) system using 1:50,000 topographic maps, (3) geo-referencing the Spot image in the same projection using the same topographic sheets, and (4) delimiting and cutting out the study watershed by tracing it from 1:50,000 topographic maps and digitising it in Arc View 3.1, then superimposing the view on the spatial databases created from the photographs and the satellite image.

The identification and classification of land cover types on the aerial photographs was undertaken by visual interpretation and required intensive use of mirror stereoscopes for visual verification because the photos were black and white. To avoid errors that can occur as details increase, the classification scheme was kept simple. Thus, seven land cover classes were identified: forest, woodlands, shrublands, farmland and settlements, grassland and degraded land, riverine trees and marshland. The 1998 land cover map contains a further class: a pond that appeared recently. A brief definition of the land cover classes is given in Table 1. The land cover classes from the Spot image were also generated by visual interpretation and on-screen digitizing using ArcInfo 7.3 on the basis of reflectance characteristics (false color composites) of the different land cover types. This was supplemented by a number of field visits that made it possible to establish the main land cover types. For the purpose of comparison, many land cover types produced from the multi-spectral Spot image were synchronized to fit into the seven classes defined from the black and white aerial photographs. In so reducing the number of classes, proper care was taken to minimize errors due to generalization.

ERDAS Imagine 8.3 and its peripheries were used to analyze the spatial databases created. Finally, three land cover maps were produced corresponding to the three reference years, and temporal changes in land cover were determined. A few focus group interviews were also conducted in four sample villages in the watershed to obtain additional information.

Table 1. Description of the land cover classes identified in the Chemoga watershed, Ethiopia

Land cover	Description
Farmland and settlements	Areas used for crop cultivation, both annuals and perennials, and the scattered rural settlements that are closely associated with the cultivated fields. Some trees, mainly eucalypts, which are commonly found around homesteads, were also included in this category.
Forest	Areas covered with dense growth of trees that formed nearly closed canopies (70-100%). This category included plantation forests, mainly eucalypts and junipers, mixed with regenerating indigenous species of trees and bushes.
Woodlands	Areas with sparse trees mixed with short bushes, grasses and open areas; less dense than the forest.
Shrublands	Areas covered with shrubs, bushes and small trees, with little useful wood, mixed with some grasses.
Grassland/ degraded land	Grassy areas used for communal grazing, as well as bare land that has very little or no grass cover (exposed rocks) but with the same tone on the air photos.
Riverine trees	Linear areas of trees and shrubs along the stream courses.
Marshland	Areas that are waterlogged and swampy in the wet season, and dry in the dry season. These are very important for grazing during the dry season.
Pond	Fed by rainfall and runoff.

Results and discussion

Dynamics in land cover types

Figure 2 shows the land cover maps of the watershed for the three reference years, and statistical summaries of the different land cover types are given in Table 2.

Forests

The area under forest cover showed a slow but persistent increase over the period under study. Though this was a general trend, the rate of increase was quite small compared with the total area of the watershed. The area under forests increased by about 19% between 1957 and 1982 (7 ha yr^{-1}) and by 27% between 1982 and 1998 (17 ha yr^{-1}). During the entire period the increase was more than 50% (about 11 ha yr^{-1}). This increase is attributable to the afforestation program of the *derg* regime, a local initiative that has preserved some indigenous trees/ forests and the planting of trees at the household level. As in many places throughout the country, the community undertook some afforestation during the *derg's* dictatorial rule. The small success achieved contributed to the present areal coverage by forests. Most of the tree species planted at that time were varieties of Junipers and eucalypts.

Area protection by the local community is another reason for the increase in forest cover; which has led to regeneration of Asta (*Erica arborea*) woodlands into forests in the upstream part of the watershed. Initiated by elders, this effective form of community forest management was established in the 1960s, as confirmed by participants of group interviews. It shows that community participation can lead to more sustainable resource use compared with a centralized system of control that strives for preservation. A centralized, top-down approach to resource conservation in Ethiopia, such as the one broadly attempted during the *derg* regime led nowhere (Azene, 1997, 2001). The other important factor for the increased areal coverage of forests is the household level planting of trees as a response to the growing scarcity of natural forests.

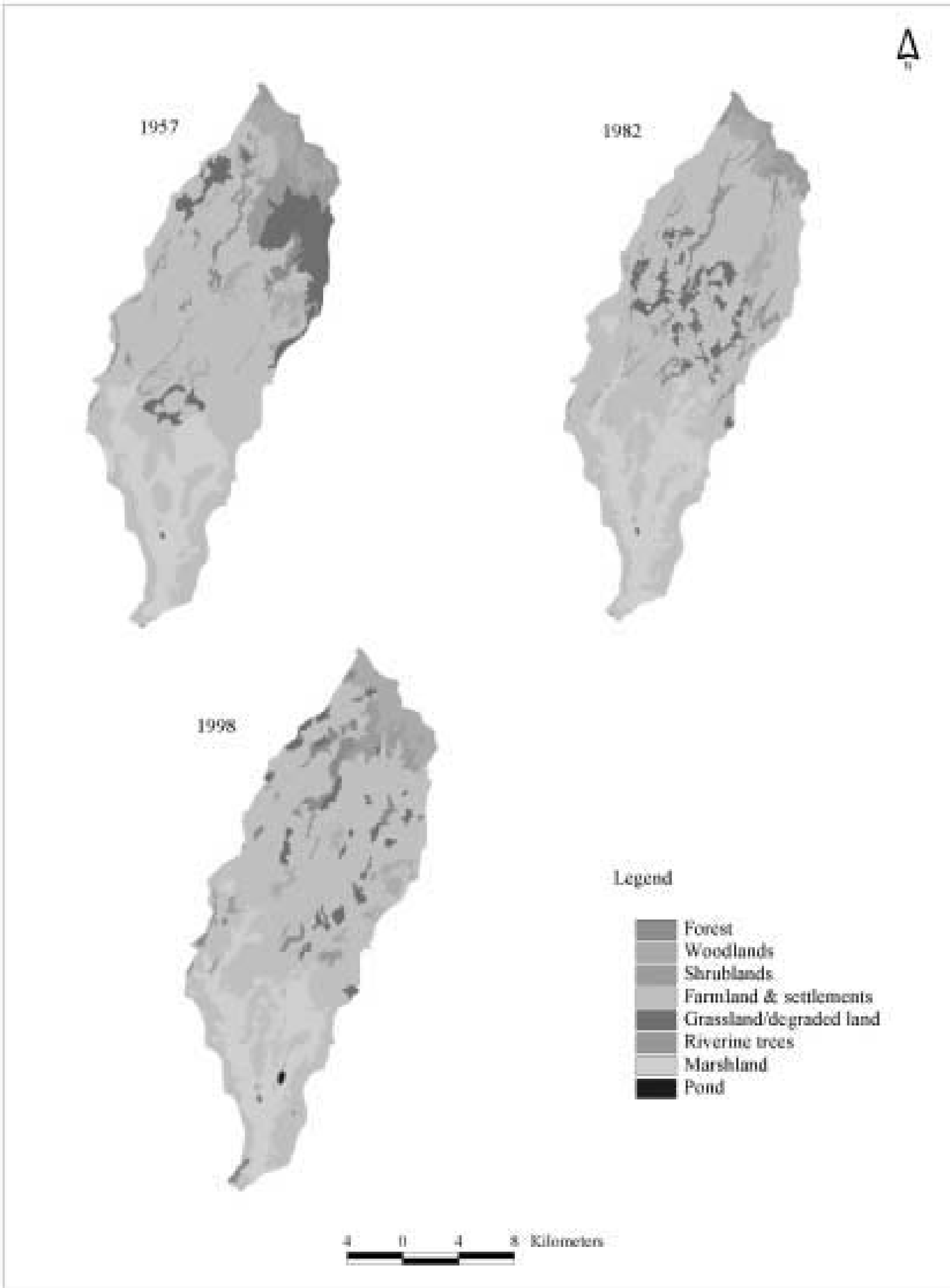

Figure 2. Land cover types in the Chemoga watershed in 1957, 1982 and 1998

Table 2. Land cover changes in the Chemoga watershed between 1957 and 1998.

Land cover type	Area in 1957 (ha)	Area in 1982 (ha)	Area in 1998 (ha)	Change between 1957 and 1982 (%)	Change between 1982 and 1998 (%)
Forest	873	1041	1321	+19	+27
Woodlands	2449	1321	2457	-46	+86
Shrublands	1860	1099	1186	-41	+8
Farmland and settlements	22000	24832	24246	+13	-2
Grassland/ degraded land	3508	1766	1276	-50	-28
Riverine trees	458	277	94	-40	-66
Marshland	5252	6064	5780	+15	-5
Pond	-	-	40	-	+100
Total	36400	36400	36400	-	-

Woodlands and shrublands

The pattern in change of woodlands and shrublands is broadly similar. Both showed a decrease in the first period and then an increase in the second. The decrease in area for woodlands was 46% between 1957 and 1982; there was a recovery to a higher level by 1998. A 41% decrease in shrublands also occurred between 1957 and 1982 but here too some reemergence of this cover type occurred between 1982 and 1998. Woodlands and shrublands combined accounted for 12%, 7% and 10% of the total area of the watershed in 1957, 1982 and 1998, respectively.

Farmland and settlements

This category includes cultivated land and settlements. These two land cover types were combined into one category because it was difficult to identify the dispersed rural settlements as a separate land cover type. Also, cultivated land exists around homesteads and would have to be recognized as such. Hence, for practical reasons, the two cover types were merged into one category. Farmland and settlements gained area between 1957 and 1982 (13% increase) but lost around 586 ha (2% decrease) between 1982 and 1998. The increase between 1957 and 1982 corresponds to the population growth and is also possibly due to the 1975 national-level land reform, which allocated much of the grazing land to landless peasants for cultivation; this was also observed in the most recent land redistribution of 1997 undertaken in the Amhara Regional State (Yigremew, 1997). The decrease in the latter 16-year period, though very small, might seem to contradict expectations, given the increase in population. But this decrease is attributable to increased tree planting at the household level, which has led to the formation of clustered plantations in formerly cultivated lands and around homesteads. These were classified as forest cover because that is how they appeared on the images.

Grassland and degraded land

Grassland and degraded land includes both open grazing lands and exposed badlands. Because it was difficult to distinguish open badlands from grazing lands, which are heavily degraded in the area, they were classified together. In 1957, grassland and degraded land covered some 9.6% of the total area of the watershed. This was reduced to 4.8% by 1982 and further diminished to 3.5% by 1998. According to the group interviews, the major reason for the decrease in the areal extent of grassland and degraded land was population pressure, which caused much of the open grazing land to be transformed into cropland. The remaining area now consists largely of bare ground, which is overgrazed and characterized by exposed rocks.

Riverine trees

The width of these strips of vegetation-covered lands along the rivers shrank continuously. In 1957, the area under riverine trees was about 458 ha. It was reduced to 277 ha by 1982 and further dwindled to 94 ha by 1998. This constitutes a 40% decrease for this type between 1957 and 1982 and a 66% between 1982 and 1998. During the 41-year period, the area covered by riverine trees decreased by around 79%, much of it lost due to cultivation.

Marshlands

The pattern of change for this land cover type is one of increase in the first period and decrease in the second. Marshland covered 14% of the total area of the watershed in 1957, 17% in 1982 and 16% in 1998. These dynamics may be due to the decrease in woodlands and shrublands and the increase in farmland and settlements between 1957 and 1982 and the increased vegetative cover (forest) between 1982 and 1998. Indeed, decrease in vegetation cover in a catchment can lead to increase in surface runoff. Such an increase in surface runoff in the upstream part can cause a greater area to be subject to wet conditions in the downstream part, thus expanding the marshland. By the same reasoning, the increased vegetative cover by 1998 may have caused increased transpiration losses and reduced catchment water yields, thereby leading to shrinkage of the marshland. The pond that appeared in the 1998 land cover map was probably part of the marshland during the first period, and it emerged in the 1998 land cover map because of shrinkage of the marshland during the second period. Indeed, the pond is unlikely to have been caused by a change in the rainfall pattern. This pond may have also provided an inlet for the water in nearby marshland, causing the surrounding area to dry up, resulting in a gain for farmland and settlements.

Causes of land cover dynamics

Land cover changes are caused by a number of natural and human driving forces (Meyer and Turner II, 1994). Whereas natural effects such as climate change are felt only over a long period of time, the effects of human activities are immediate and often radical. Population growth is the most important of the human factors in Ethiopia (Hurni, 1993), as it generally is the case in underdeveloped countries (Hurni, 1993; Mortimore, 1993). It was not possible to obtain overall demographic data for the watershed studied here because such data are compiled according to administrative structures (peasant associations, districts and provinces; and data do not correspond to watershed boundaries). But changes in population in four sample villages in the watershed between 1984 and 1994 are given below, making it possible to gain insight into the magnitude and rate at which the population has been increasing (Table 3).

Table 3. Population growth in four villages in the Chemoga watershed between 1984 and 1994

	Population		Growth between 1984 and 1994	Rate of growth (%)[a]	Number of years after which the population will have doubled (after 1994)
	1984[b]	1994[c]			
Dangule	3469	5121	1652	3.89	18
Keny	3025	4102	1077	3.05	23
Sinan	2865	3990	1125	3.31	21
Yegagna	3268	3570	302	0.88	78
Total	12627	16783	4156	2.85	24

[a]The growth rates were calculated on the basis of the assumption of exponential increase: $P_t = P_o e^{rn}$.
Hence, $r = 1/n \ln (P_t/P_o)$; the doubling period in years is given as ln2/r.
[b]Source: OPHCC (1990)
[c]Source: OPHCC (1995)

The total population of the watershed at the time fieldwork for this study was carried out was around 40,768. Assuming that the average rate of population increase in the four sample villages (2.85%) remained constant in the whole watershed, the population of the watershed would have been half its current size about 25 years ago. By the same reasoning, it will double within less than 25 years from now. Thus, population growth was certainly the most important factor causing change in the observed land cover dynamics because demand for land for cultivation and settlement and trees for fuel and construction purposes was greater. As mentioned above the scarcity of trees motivated the local population to plant and protect trees.

Implications of land cover dynamics

Implications for soil degradation

Land cover is one of the factors that determine the rate of soil loss due to erosion. It influences both the erosivity of the eroding agents and the erodibility of the eroding subject (Morgan, 1995). From the point of view of exposure of the land to erosive storms, which are typical in the area, the land cover types in the watershed can be classified into two classes: (1) land that is bare when the erosive rains occur, and (2) land under good vegetative cover when the rains begin, which is protected from the threat of erosion. Cultivated fields and part of the grassland and degraded land constitute the first category, whereas the rest of the land cover types can be included in the second. Accordingly, the part of the watershed subject to possible maximum soil loss accounted for 70%, 73% and 70% of the total area in 1957, 1982 and 1998, respectively. Thus the total area exposed to major erosion remained almost constant between 1957 and 1998. The slight increase in forest cover in the watershed does not imply less severe erosion because most of the newly forested areas consist of eucalypts, which hardly reduce erosion due to their sparse canopies (FAO, 1988).

Implications for the hydrological balance in the watershed

Land cover changes interfere with the land phase of the hydrological cycle. As is well known, land under little vegetative cover is subject to high surface runoff and low water retention. The increased runoff causes sheet erosion to intensify and rills and gullies to widen and deepen. The masses of sedimentary materials removed from hillslopes accumulate in low-lying areas downstream, where they create problems of water pollution, reservoir siltation and problematical sediment deposition on important agricultural lands. These problems have already emerged in the study watershed, as was clearly stated by the local population during focus group interviews and also observed in the field. Extensive flooding and sedimentation problems occur in the watershed's downstream marshland area. According to local informants, this has become a major problem because valuable grassland is 'buried', which makes it unusable for grazing. According to the above grouping of land cover types into two classes, the total area of possible maximum runoff remained more or less the same between 1957 and 1998. Also, the observed increase in afforested areas did not improve the hydrological balance in the watershed because eucalypt trees, which are widely planted, are known to absorb a great amount of water.

Conclusions

Land cover changes have occurred in the Chemoga watershed during the forty-one years considered here. But agriculture has remained the main type of land use, with its implications on increased runoff, erosion, flooding, and sedimentation problems. A general trend toward 'more people more trees' was observed, contrary to the findings of other studies (e.g. EFAP, 1993; Gete, 2000; Kebrom and Hedlund, 2000). This is the result of community afforestation, a local initiative that has preserved some indigenous forests and the planting of trees at the household level. The household level tree planting practice is a commendable initiative because it can have economic as well as ecological benefits, provided the main species of tree is not eucalypts, which has many negative ecological effects (FAO, 1988). Planting of trees at the household level should therefore be encouraged by providing farmers with ecologically friendly multipurpose species. The local initiative to preserve indigenous forests also has an important policy implication, i.e., the need to involve local people and exploit the influence of village elders to implement effective resource management in the country. Finally, the status of land cover and its dynamics have environmental implications at the local scale as well as beyond because the consequences of degradation know no boundaries. For instance, downstream sedimentation caused by upstream degradation is already a problem in the study watershed. There is, therefore, a need for interregional and international cooperation to improve environmental management. A logical framework for such cooperation is to use watersheds as regional constructs and to pursue an integrated watershed management approach for conservation planning and development of resources.

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Chapter 3

Effects of agro-ecological land use succession on soil properties in the Chemoga watershed, Blue Nile basin, Ethiopia

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Effects of agro-ecological land use succession on soil properties in the Chemoga watershed, Blue Nile basin, Ethiopia

Abstract

This study appraises the effects of land use on soil properties in a typical watershed in northwestern highland of Ethiopia. Soil samples were collected from major land use types in the watershed: natural forests, cultivated lands, grazing lands and *Eucalyptus* plantations. The natural forests served as a control against which to assess changes in soil properties resulting from the establishment of the other land use types. Samples were taken at two depths (0-15 and 15-30 cm) in the upstream and downstream areas of the watershed and analyzed for a range of soil properties. The soils in the cultivated fields, grazing lands and *Eucalyptus* plantations showed significantly higher sand content, but lower Ca^{2+} and Mg^{2+} contents and cation exchange capacity compared to soils under natural forests. *Eucalyptus* soils had a statistically significant higher bulk density than soils under the other three land use types. The forest and *Eucalyptus* soils also differed significantly from each other in their soil organic matter and total N contents. A significant difference in available P among soils of the four land use types was caused by the difference between cultivated and *Eucalyptus* soils. In contrast, the distribution of soil silt fraction, Na^{+}, K^{+} and pH values did not differ among the four land use types. Significant differences in many of the soil properties were also observed between soils in the two sampled villages. The study underscores the need for policies and strategies for sustainable land use that will attune objectives of economic development to environmental management at the regional and local levels.

Key words: land use change, *Eucalyptus*, grazing, sustainability, policy

Introduction

As is the case in many other developing countries, most of the population of Ethiopia lives in rural areas and depends directly on the land for its livelihood. This rural population is currently growing rapidly, and consequently inducing many effects on the resource base. One such effect is a very dynamic land use and land cover. This has been confirmed by empirical studies carried out in different parts of the country (Solomon, 1994; Kebrom and Hedlund, 2000; Gete and Hurni, 2001). A common concern addressed by many of these studies is the resource degradation brought about by the decrease in the area under natural vegetation and its conversion into other types of land use and land cover that are human-managed systems. The underlying simple assumption is that de-vegetation leads to deterioration in the physical and chemical properties of soils and degradation of the land. However, for the concern to be justified, the assumption must be based on sound empirical evidence.

Empirical studies are deficient in Ethiopia, but others conducted elsewhere in the world have attempted to evaluate effects of changes in land use and land cover on physical and chemical properties of soils. For example, Lumbanraja et al. (1998) found out that with conversion of primary forests to secondary forests, coffee plantations and cultivated land in south Sumatra, Indonesia, soil organic C, total N, available P, total P and exchangeable cations contents and cation exchange capacity (CEC) of the soil decreased significantly. In a study in the Zagrous Mountains of Iran, Hajabbasi et al. (1997) reported an increase in bulk density (BD), and decreases in soil organic matter (SOM), total N and soluble ions contents following deforestation. In Orissa, India, conversion of forest into farmland led to a significant reduction in organic carbon, total N and C: N ratios, but not in total and available P levels (Saikh et al., 1998a). Similarly, Lal (1996) concluded that soils in western Nigeria deteriorated in chemical properties after deforestation and with cultivation time, regardless of differences in cropping systems.

On the other hand, in their study in Orissa, India, Saikh et al. (1998b) reported that 'deciduous forest, grassland and cultivated soils have statistically similar contents of exchangeable Ca^{2+}, Mg^{2+}, K^{+} and Na^{+}'. In a comparison of soil samples collected in 1969 and 1996 in eastern Burkina Faso, there was no indication of declining fertility of the soils that could be ascribed to agricultural use of the land (Mazzucato and Niemeijer, 2000). Using a similar approach, Gray (1999) did not find a significant deterioration of soil chemical properties from 1988 to 1996 for a village in southwestern Burkina Faso, while aerial photos of the area showed increases in areas labeled as degraded. These contrasting findings suggest that the assumption that conversion of natural vegetative cover into human-managed systems leads to deterioration in the physical and chemical properties of soils and degradation of the land is not always valid. There is clearly a need for empirical investigations into the problem.

Establishing effects of land use and land cover changes on soil properties has implications for devising land management strategies for sustainable use. The information can be employed to forecast the likely effects of any potential changes in land use on soil properties. As it is well known, for instance, the destruction of vegetative cover can promote soil erosion, which eventually increases the magnitude of soil-related constraints to crop production (Stroosnijder and Eppink, 1993). Generally, a sound understanding of land use effects on soil properties provides an opportunity to evaluate sustainability of land use systems. Hence, as Lal (1996) puts it, 'understanding the basic processes of soil degradation in relation to land use, and soil and crop management must be allocated a high research priority' (p. 97).

Though there is abundant literature on the magnitude and rate of soil erosion in the highlands of Ethiopia, changes in soil physical and chemical properties associated with land use are poorly documented. The objective of this paper was, therefore, to study some physical and chemical properties of soils under different land use systems in a typical watershed in the northwestern highlands, with a view to evaluate the effects of land use.

Land use/ cover dynamics in Chemoga watershed since the 1950s

Site information

The Chemoga watershed is located in the northwestern highlands of Ethiopia, within 10^0 18' N to 10^0 39' N and 37^0 44' E to 37^0 53' E (Fig.1 in Chapter 2). It is characterized by a humid climate. At Debre-Markos ($10^0$20'N, $37^0$40'E and elevation 2411m), the mean annual temperature is 14.5 ^{0}C and the mean annual rainfall is 1300 mm. Since the Chemoga watershed is at a higher elevation (between 2420 and 4000 m) than Debre-Markos, the temperature is lower and rainfall probably higher than these values, but no exact values are available.

Geologically, the watershed is part of the highlands that largely owe their altitude to the uplift of the Arabo-Ethiopian landmass and the subsequent outpouring of basaltic lava flows during the Tertiary period. Thus, the surface geology is of basaltic rocks, which are the parent materials for the overlying soils (Mohr, 1971).

The physiography of the watershed reflects its geologic history. The uplift created an elevated landmass and the subsequent lava emission provided a thick protective cap and added to the altitude. This landscape has been subjected to geomorphic processes which have significantly reshaped it. Currently, the Chemoga watershed is characterized by diverse topographic conditions. The elevation ranges from 2420 m to nearly 4000 m, and slopes range from nearly flat (<2%) to very steep (>55%). The upstream part is characterized by a mountainous and highly dissected terrain with steep slopes, and the downstream half is characterized by an undulating topography and gentle slopes.

The soils in the watershed that cover much of the total area can be classified into three types on the basis of their color: dark brown, reddish and grayish (gray to dark). The dark brown soils belong to the Andosols soil associations, the reddish soils belong to the Nitisols and the grayish soils belong to the Fluvisols, according to the FAO/Unesco (1990) soil classification system. The dark brown soils are at high altitudes with a temperate- and alpine-like climate, and cover a large area in the upstream part of the watershed. Owing to the nature of the agro-climate, only few types of crops are grown in these areas. The reddish soils occur on nearly level to gently undulating land that is well drained. These soils largely occupy the midstream and downstream parts of the watershed. They constitute the most intensively utilized types, on which the subsistence-oriented farmers of the region grow a variety of crops. The grayish (gray to dark) soils occur in the floodplains in the downstream reaches of the watershed, where alluvial sediment is deposited every wet season. Because of the regular flooding, these floodplains are not used for crop production. However, they constitute a very important area of livestock grazing, particularly during the dry season, when the good reserves of soil moisture keep the grass green. The farming system of the region is a typical mixed crop–livestock system at subsistence scale.

Land use changes

The land use patterns in the Chemoga watershed, which were obtained by interpretation of aerial photos and a multi-spectral Spot image, are given in Tables 1 and 2. Details of land use dynamics in the watershed over the period between 1957 and 1998 are given in Woldeamlak (2002). Only a summary is given below, and for clarity a brief definition of the various land use types is given in Table 1.

By 1957, most of the area was occupied by farmland and settlement (60%), distantly followed by marshland (14%) and grassland/ degraded land (10%). Woodlands and shrublands covered some 7 and 5% of the total area of the watershed, respectively. The area coverage of forest was more than 2% of the total, and riverine trees accounted for about 1% of the total area. Between 1957 and 1982 the area under forest, farmland and settlement, and marshland increased. Woodland, shrubland and grassland/ degraded land decreased. The decline was greatest for the grassland/ degraded land areas followed by woodland. By 1998, the farmland and settlement still covered the largest area (67% of total area), but decreased slightly between 1982 and 1998, similar to grassland/ degraded land, riverine trees and marsh. Areas under forest and woodland increased between 1982 and 1998. A new pond of 40 ha emerged in the marshland between 1982 and 1998.

Table 1. Description of the land use/ cover classes identified in Chemoga watershed, Ethiopia

Land use/ cover	Description
Farmland and settlement	Areas used for crop cultivation, both annuals and perennials, and the scattered rural settlements that are closely associated with the cultivated fields. Some trees, mainly eucalyptus, which are commonly found around homesteads, were also included in this category.
Forest	Areas covered with dense growth of trees that formed nearly closed canopies (70-100%). This category included plantation forests, mainly eucalyptus and junipers, mixed with regenerating indigenous species of trees and bushes.
Woodlands	Areas with sparse trees mixed with short bushes, grasses and open areas; less dense than the forest.
Shrublands	Areas covered with shrubs, bushes and small trees, with little useful wood, mixed with some grasses.
Grassland/ degraded land	Grassy areas used for communal grazing, as well as bare land that has very little or no grass cover (exposed rocks) but with the same tone on the air photos.
Riverine trees	Linear areas of trees and shrubs along the stream courses.
Marshland	Areas that are waterlogged and swampy in the wet season, and dry in the dry season. These are very important for grazing during the dry season.
Pond	Fed by rainfall and runoff.

The major change over the four decades is the increase of the cultivated area at the expense of the open grazing area. Unexpectedly, the forest cover has shown a slight increase and is now of the same importance (4% cover) as the grassland/ degraded land (largely used for grazing). This increase is attributable to the afforestation activities during the *derg* regime, a local initiative that has preserved some indigenous trees/forests and the planting of trees by households (Woldeamlak, In press). The tree species widely planted by the afforestation activities as well as by the farm households is *Eucalyptus*. *Eucalyptus* plantations, therefore, are now an important land use type in the watershed. The trees are planted around homesteads as well as in fields further away, where they are grown in larger blocks. In the case of the latter, establishment of the *Eucalyptus* plantations appears to be the last in an agro-ecological succession of land use types in the area. The succession involved clearing the climax vegetation cover and cultivating the land. To counteract decline in fertility of the land due to cultivation, farmers used to practice fallowing. When the farmers felt the land fertility was restored, fallowed fields were taken back into cultivation. This practice has now been largely abandoned, however, because of the land shortage; instead, continuous cultivation has become the standard practice. In some areas too degraded for crop production *Eucalyptus* have been planted. This has implications for the current fertility status of soils under *Eucalyptus*.

Table 2. Land use changes between 1957 and 1998 in the Chemoga watershed, Ethiopia (The total area is 36400 ha)

Land use	1957 cover (%)	1982 cover (%)	1998 cover (%)
Farmland and settlement	60	68	67
Forest	2	3	4
Woodlands	7	4	7
Shrublands	5	3	3
Grassland/ degraded land	10	5	4
Riverine trees	1	1	0
Marshland	14	17	16
Pond	0	0	0.1

Materials and methods

In the absence of prior information, changes in soil properties induced by land use dynamics have to be evaluated by establishing experimental plots under different land use treatments and monitoring them for a long time, which is costly. An alternative approach is to take soil samples from plots of land under different land use systems and compare their physico-chemical properties with soils under natural or semi-natural vegetation that has been little disturbed in its history. This approach substitutes space for time and may be called a spatial analogue method. A prerequisite for this method is that the reference vegetation community and the land use treatments must be located such that differences in geologic, topographic and climatic conditions are negligible. Under this condition, any differences in soil properties can be attributed to the differences in land use types. Because of this assumption, however, the conclusions drawn would remain provisional. This approach has been employed in several studies (e.g. Abubakar, 1996 and 1997; Hajabbasi et al., 1997; Lumbanraja et al., 1998; Jaiyeoba, 1998).

The present study also used this inferential approach. Thus, soil samples were collected from two sites and four major land use types. The sites were Dangule (3200–3500m) and Yegagna (2500–2600m) villages, located respectively upstream and downstream of the watershed (Fig. 1 in Chapter 2). The land use types were semi-natural vegetation (forest), cultivated land, open grazing areas and *Eucalyptus* plantations. The soils sampled belong to the dark brown soils (in Dangule) and the reddish soils (in Yegagna). The criterion considered when choosing these sampling villages was land use, and not the type of the soils, as the objective was to study variations in the soils properties with respect to differences in the land use types. In both of the villages, the natural vegetation community has been intact as long as the local people can remember, the cultivated and grazing areas have been under the current use continuously for at least two decades, and the *Eucalyptus* plantations were more than a decade old. In both the sampling sites, the four land use types are too close to each other to differ in environmental attributes. *Erica arborea* is the dominant tree species in natural forests at Dangule, while *Juniperus procera*, *Acacia etbaica* and *Carisa edulis* are dominant plant species in Yegagna. Barley (*Hordeum vulgare*), oats (*Avena sativa*), horse beans (*Vicia faba*) and potatoes (*Solanum *tuberosum*) are the only crops grown in Dangule. In addition to these crops, wheat (*Triticum vulgare*) and tef (*Eragrostis tef*) are grown in Yegagna.

At the two sampling locations and for every land use type, soil samples were taken at two depths: 0-15 cm (surface layer) and 15-30 cm (subsurface layer) in three replicates, which were located some 50 m apart from each other. Each of the replicates consisted of five sub-samples in composite, which were collected at random positions within a 10 m x 10 m plots. The two depths were chosen so that the surface layer represents the average plough depth and the subsurface layer represents the depth to which clay particles migrate and at which nutrients leached from the top layer accumulate. At each of the sites and depths two categories of samples were taken: an undisturbed sample, taken with a known volume, and a sample taken with a soil auger. The first group of samples was used to determine the BD of the soils. The second category of samples was used to determine the other soils properties described in this paper.

The samples used for the laboratory analysis were first air-dried, lightly ground and screened through a 2 mm sieve. Then, the conventional analytical methods were employed following procedures described in MoNRDEP (1990). Texture was determined by the hydrometer method, pH by using a pH meter in a 1:2.5 soil: water ratio and soil organic carbon by the Walkley-Black oxidation method. The percent SOM was calculated by multiplying the percent organic carbon by a factor of 1.724, following the standard practice that organic matter is composed of 58% carbon (Brady, 1985). Total N was determined by the Kjeldahl digestion, distillation and titration method, available P by the Olsen extraction method and exchangeable bases by the ammonium acetate extraction method, and from the extracts, concentrations of Ca and Mg were determined by atomic absorption spectrophotometery, and K and Na by flame emission. The CEC was determined by summation of cations.

The two-way analysis of variance (ANOVA) with the land use types and the sampled sites (villages) as the main factors was used to test significance of mean differences in properties of the soils (at α of 0.05). After computing the ANOVA, all soil properties that showed significant differences among the land uses were subsequently analyzed for the significance of mean differences between each two of the land use types employing the Scheffé *post hoc* multiple comparisons test (at α of 0.05). The statistical analysis was undertaken using the GLM procedure of the SPSS release 10 (Bryman and Cramer, 2001).

Results and discussion

Table 3 shows average values of soil properties for each of the four land use types, and overall averages of the four land use types in the two sampling sites. There were large differences between the two villages. At Dangule, soils were low in clay but high in SOM. This leads to high pH and low BD. The soil nutrient status was better than in Yegagna. At Yegagna, SOM, pH and nutrient availability were much lower. In many cases, the forest soils showed the best soil properties for plant growth and *Eucalyptus* plantations the worst. The results of the ANOVA intended to assess the significance of variations in the soil properties among the four land use types and between the two sites, and a more detailed *post hoc* multiple comparisons test are displayed in Tables 4 and 5, respectively.

Soil texture

In both villages, the sand fraction was lowest in the forest plots and highest in the cultivated fields (Table 3). The clay fractions, on the other hand, were highest in the forest plots and lowest in both the cultivated and grazing fields. Sand and clay contents but not silt content differed among the land use types (Table 4). The Scheffé test revealed that the forest soils differed from all the others in terms of sand content (Table 5). The general trend in soil texture after forest has been converted into the other types of land use has therefore been an increase in the sand and a decrease in the clay contents. Under sparser vegetation covers the clay fractions are likely to be lost to processes of selective erosion and migration down the soil profile. The latter was evident from the fact that in most of the samples the clay contents of subsurface layers were higher than the overlying surface layers (data not shown).

Bulk density

The BD of the soils was generally low. It was lowest in areas under forest, and highest in areas of *Eucalyptus* (Table 3). The ANOVA indicated significant difference among the land use types (Table 4). *Eucalyptus* soils had a higher BD than the other land use types (Scheffé test; Table 5). Thus, there is a general pattern of *Eucalyptus* plantations to be associated with soil compaction, which has implications for the moisture and air that would be available to life forms in the soil system. The replacement of forest by *Eucalyptus* should be seen as the replacement of a pristine by a final agro-ecological type. The BD difference between soils in the two villages (Table 4) is attributable to, among others, the differences in SOM content and the types of the soils. The interaction effect of land use and site was also statistically significant, mainly caused by the significant difference between the two sites.

Table 3. Soil properties (top 0-15 cm) under the four land use types in Chemoga watershed, Ethiopia

	Dangule					Yegagna				
Soil property	Forest	Cultivated	Grazing	Eucalyptus	Average	Forest	Cultivated	Grazing	Eucalyptus	Average
Sand (%)	29	41	35	35	35	14	37	27	22	25
Silt (%)	49	44	47	47	47	23	29	37	31	30
Clay (%)	21	15	18	18	18	63	34	37	47	45
BD (g $^{cm-3}$)	0.6	0.6	0.7	1.0	0.7	0.9	1.1	1.0	1.2	1.0
PH	6.9	7.2	7.1	7.0	7.0	5.5	6.1	5.6	5.1	5.6
SOM (%)	26.3	22.9	22.4	4.4	19.0	7.8	0.9	4.1	6.0	4.7
Total N (%)	1.0	0.8	0.9	0.4	0.8	0.3	0.1	0.2	0.2	0.2
Avail. P (ppm)	12.2	35.8	25.6	8.0	20.4	7.2	8.1	3.1	1.5	5.0
CEC (meq. 100g^{-1})	30	16	18	10	18	50	13	12	20	24
Ca^{2+} (meq. 100g^{-1})	18.4	12.4	13.1	7.9	12.9	30.1	8.4	7.6	14.6	15.2
Mg^{2+} (meq. 100g^{-1})	10.7	2.5	2.5	1.3	4.2	18.8	3.8	3.0	4.6	7.6
Na^{+} (meq. 100g^{-1})	0.6	0.5	0.6	0.4	0.5	0.5	0.5	0.4	0.5	0.5
K^{+} (meq. 100g^{-1})	0.5	0.6	1.5	0.2	0.7	0.9	0.4	0.4	0.4	0.5

The observed differences between the two sampled villages have practical implications. First, soil properties can best be monitored at the local scale, as the nature of soils and processes of degradation vary continuously across space and second, soil management and fertilizer application recommendations need to be fine-tuned to site-specific conditions.

Table 4. Results of the two-way analysis of variance of properties of the soils under the four land use types and the two sites in Chemoga watershed, Ethiopia (P < 0.05 indicates significant differences)

Soil property	Land use		Site		Interaction	
	F	P	F	P	F	P
Sand	11.583	0.000	25.185	0.000	1.671	0.213
Silt	1.047	0.395	46.707	0.000	2.393	0.107
Clay	4.290	0.018	52.963	0.000	2.697	0.081
BD	22.744	0.000	89.516	0.000	6.280	0.005
SOM	5.354	0.008	45.047	0.000	90.556	0.000
Total N	6.352	0.004	97.316	0.000	13.606	0.000
Available P	4.892	0.011	14.961	0.001	2.534	0.094
Ca^{2+}	7.583	0.002	0.808	0.380	4.312	0.021
Mg^{2+}	39.534	0.000	12.560	0.002	5.964	0.006
Na^{+}	0.858	0.480	1.519	0.233	2.620	0.087
K^{+}	2.256	0.115	0.915	0.351	3.857	0.030
CEC	14.018	0.000	2.459	0.133	5.279	0.010
pH	4.121	0.059	145.075	0.000	2.316	0.115

Organic matter

As expected, the SOM content of soils under forests was the highest (Table 3). By comparison with the forest plot, the soils under cultivation, grazing and *Eucalyptus* in Dangule had average (two depths) SOM contents of 87%, 85% and 16%, respectively, and in Yegagna 11%, 53% and 78% of that in the forest plot. It seems that the conversion of forest into the other types of uses has led to a drop in SOM contents. However, we are unable to explain the differences between the land use types of the two villages. The ANOVA also revealed significant difference among the land use types (Table 4). However, the significant difference was only between the forest and *Eucalyptus* soils (Table 5).

The SOM content of soils in Dangule was much higher than that in Yegagna, and the content was very high for tropical soils. Three factors are responsible for this: the relatively low temperatures, which slow down the decomposition of SOM; the higher soil moisture contents that create conditions of poor aeration (slow oxidation); and differences in clay minerals. The intensity of erosion, which is more severe in Yegagna than in Dangule, also influences the SOM content of soils. In the cultivated fields, the types of crops grown might also contribute to the observed differences. Land use practices that have detrimental effects on SOM contents have far-reaching implications because of the multiple roles SOM plays in soil quality (Wild, 1996).

Total nitrogen

The total N content of the soils showed variation among the land use types and between the villages, matching the SOM distribution. It reached a maximum of 1.0% in the surface soils under forest in Dangule and a minimum of 0.1% in cultivated fields in Yegagna. The average (two depths) total N content of soils in Dangule decreased from forest to grazing lands to cultivated lands and *Eucalyptus* plantations, and in Yegagna, from forest to grazing lands to *Eucalyptus* plantations and cultivated fields (Table 3). The significant difference between the two sampling villages (Table 4) is due to differences in SOM content, climatic factors, intensities of erosion and leaching, soil texture, types of crops grown, and intensity of cultivation. Significant interaction between land use and site was also shown by the ANOVA, which was mainly due to the significant difference between the two sites. In all the land use types and in both villages, total N content was higher in the surface layer than in the subsurface layer, as was the SOM distribution.

Table 5. Results for the Scheffé *post hoc* multiple comparisons test[a] of properties of the soils under the four land use types in Chemoga watershed, Ethiopia

Soil property	Significant contrasts	P
Sand	Forest and cultivated	0.000
	Forest and grazing	0.038
	Forest and eucalyptus	0.024
Clay	Forest and cultivated	0.030
BD	Forest and eucalyptus	0.000
	Cultivated and eucalyptus	0.000
	Grazing and eucalyptus	0.001
SOM	Forest and eucalyptus	0.009
Total N	Forest and eucalyptus	0.006
Available P	Cultivated and eucalyptus	0.015
Ca^{2+}	Forest and cultivated	0.008
	Forest and grazing	0.008
	Forest and eucalyptus	0.014
Mg^{2+}	Forest and cultivated	0.000
	Forest and grazing	0.000
	Forest and eucalyptus	0.000
CEC	Forest and cultivated	0.000
	Forest and grazing	0.001
	Forest and eucalyptus	0.001

[a] Only comparisons where differences are statistically significant are given.

Available phosphorus

The available P content ranged from 8 ppm to 36 ppm in Dangule and 1.5 ppm to 8 ppm in Yegagna (Table 3), highest in cultivated fields and lowest in *Eucalyptus* plantations in both villages. The higher available P content of cultivated fields than forest suggests that trees in forests extract more phosphorus than field crops and/ or that a high proportion of the P pool is retained and immobilized by microbes in the litter layers of forests and *Eucalyptus* plantations (Lisanework and Michelsen, 1994). Another possibility is that the effect of applying cattle dung as a soil conditioner in cultivated fields has been substantial. Furthermore, available P levels were lower in the forest soils than in the cultivated fields, despite the higher SOM contents of the forest soils indicating the significance of inorganic sources of P. Generally, the pattern of distribution of available P among the land use types suggests that the effect of deforestation and establishment of the other types of use on availability of this vital nutrient was not negative. The only significant difference in the available P was between the cultivated and *Eucalyptus* soils (Table 5). A similar finding—that is, insignificant change in available P following deforestation—was reported by a study in tropical India (Saikh et al., 1998a). In our study, there was a statistically significant higher available P content in Dangule than in Yegagna (Table 4). The difference is attributable to differences in SOM content and pH of the soils, severity of erosion and leaching, and types of crops grown and intensity of cultivation. Irrespective of the land use types, the available P content of soils in Yegagna was at deficiency level.

Exchangeable cations and CEC

The CEC of the soils ranged from 14 meq to 37 meq per 100 g soil, lowest under cultivation and highest under forest. The difference among the land use types was significant, as shown by the *F*-test (ANOVA), and the CEC under forest was higher than the other three land use types, as shown by the Scheffé test. The CEC of soils is determined by their SOM content and the amount and type of clay minerals present, with the role of SOM far exceeding the role of clay. CEC is crucial in soil fertility for two fundamental reasons: (i) the total quantity of nutrients available to plants as exchangeable cations depends on it, and (ii) it influences the degree to which hydrogen and aluminum ions occupy the exchange complex, and thus affects the pH of soils (Olaitan et al., 1986). There was no statistically significant difference between soils in the two sampled villages in terms of the CEC. The significant interaction effect between land use and site was caused only by the higher CEC of forest soils in Yegagna. The Ca^{2+} accounted for the lion's share of the CEC followed by Mg^{2+}.

The soils under the four land use types significantly differed in Ca^{2+} content (Table 4), with higher content being in forests (Scheffé test; Table 5). But, villages did not differ statistically. Very similar patterns were observed for Mg^{2+}. It was highest under forest in both villages, and lowest under *Eucalyptus* in Dangule and under grazing in Yegagna. In terms of Mg^{2+} content, soils in Yegagna were richer than soils in Dangule, the difference being statistically significant. This may be ascribable to the higher Ca^{2+} content of the soils in Dangule, which is held more strongly than Mg^{2+} in the colloidal complex (Olaitan et al., 1986). The general trend in these two essential plant nutrients is a decrease with conversion of forest into the other types of land use.

The K^+ and Na^+ contents of the soils show statistically insignificant differences among the land use types and between the villages. This suggests the absence of any effect that can be linked to land use dynamics in the watershed. These findings on the exchangeable bases content of the soils under the different land use types agree with those of Saikh et al. (1998b), who reported a significant decrease in Ca^{2+} and Mg^{2+}, but insignificant changes in K^+ and Na^+ levels after conversion of forest to farmland.

Soil pH

The variations in the pH of soils under the different land use types were generally small (Table 3). In Yegagna, the soils were moderately acidic (pH ranging from 5.1 to 6.1), while in Dangule they were slightly alkaline (pH ranging from 6.9 to 7.2). Soil pH influences plant growth directly, via the effect of the hydrogen ions, and indirectly, via effects on nutrient availability. The latter is more important (Brady, 1985). The lower soil pH in Yegagna can be attributed to the more intense erosion and leaching processes. In both villages and irrespective of the land use types, the soil pH was higher in the subsurface layers than in the surface layers.

Conclusions

In the Chemoga watershed, soils in cultivated fields, grazing lands and *Eucalyptus* plantations showed significantly higher sand content, but lower Ca^{2+} and Mg^{2+} contents and CEC compared to soils under natural forests. *Eucalyptus* soils had a statistically significant higher BD than soils under the other three land use types. The forest soils also had higher SOM and total N contents than soils under *Eucalyptus* plantations, the difference being statistically significant. A significant difference was also observed in the distribution of available P among soils of the four land use types, but the significant difference was only between the cultivated and *Eucalyptus* soils. In contrast, differences in the distribution of soil silt fraction, Na^{+}, K^{+} and pH values among the four land use types were statistically insignificant, suggesting absence of a considerable effect that could be directly associated with land use dynamics. The fact that forest soils showed the highest nutrient contents and cultivated and *Eucalyptus* soils, in most cases, the lowest suggests that the general trend in the land use change in the watershed has not been beneficial to the soils.

In most cases, the soils under *Eucalyptus* plantations, which have increasing cover since the 1950s, were of the poorest quality. This implies either that the tree has been planted in already degraded lands and is poor in restoring soil fertility, or that it is not a good substitute for indigenous trees and natural forests in mediating soil fertility. Michelsen et al. (1996) also reported higher values of total N, available P and Ca^{2+} in natural forest soils compared to soils under five of the most common plantation species in highland Ethiopia, three of which were *Eucalyptus*. A similar finding was reported by Jaiyeoba (1998) in his study in northern Nigeria; he concluded that *Eucalyptus* trees ‘have a definite degradative effect on soil properties’. Indeed, *Eucalyptus* is commonly accepted to have a number of negative ecological effects along with its economic benefits (FAO, 1988). Therefore, though the area under forest cover (including *Eucalyptus*) has increased, the general trend in the land use and land cover dynamics in the study watershed has not been to the benefit of the soil resource. This emphasizes the need for appropriate policy and technical interventions in the farmers’ tree planting practices, to ensure sustainable land management. The finding also indicates that land use and land cover changes alone are insufficient indicators of the state of land degradation, and that an integrated approach is needed for land degradation assessment and effective resource management.

Our finding of significant differences between many of the soil properties in the two sampled villages has two important policy implications. The first is that any intervention in soil management should be location-specific and the blanket recommendations for fertilizer application and soil and water conservation, which are now the norm in Ethiopia, should be changed. The second is that the severity of land degradation varies over space and time; hence, local level investigation is essential to design local-specific and appropriate rehabilitation and management interventions.

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Chapter 4

Dynamics in land cover and its effect on stream flow in the Chemoga watershed, Blue Nile basin, Ethiopia

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Submitted to Hydrological Processes

Dynamics in land cover and its effect on stream flow in the Chemoga watershed, Blue Nile basin, Ethiopia

Abstract

The objective of this study was to analyse changes in stream flow patterns with reference to dynamics in land cover/use in a typical watershed, the Chemoga, in northwestern highland Ethiopia. The results show that, between 1960 and 1999, total annual stream flow decreased at a rate of 1.7 $mmyr^{-1}$, whereas the annual rainfall decreased only at a rate of 0.29 $mmyr^{-1}$. The decrease in the stream flow was more pronounced during the dry season (October to May), for which a statistically significant decline (0.6 $mmyr^{-1}$) was observed while the corresponding rainfall showed no discernible trend. The wet season (June to September) rainfall and stream flow did not show any trends. Extreme low flows analysed at monthly and daily time-steps reconfirmed that low flows declined with time, the changes being highly significant statistically. Between 1960 and 1999, the monthly rainfall and stream flow amounts of February (month of lowest long-term mean flow) declined by 55% and 94%, respectively. Similarly, minimum daily flows recorded during the three driest months (December to February) showed statistically highly significant declines over the same period. It declined from 0.6 m^3s^{-1} to 0.2 m^3s^{-1} in December, from 0.4 m^3s^{-1} to 0.1 m^3s^{-1} in January and from 0.4 m^3s^{-1} to 0.02 m^3s^{-1} in February. In contrast, extreme high flows analysed at monthly (for August) and daily (July to September) time-steps did not reveal discernible trends. The observed adverse changes in stream flow have apparently resulted from changes in land cover/use and/or degradation of the watershed that involved expansion of croplands at the expense of natural vegetative covers, overgrazing and increased area under eucalypt plantations. Given the significance of the stream flow as the only source of water to the local people, a set of measures aimed at reducing magnitudes of surface runoff generation and increasing groundwater recharge are required to sustain the water resource and maintain a balanced dry season flow in the watershed. Generally, integrated watershed management (IWM) approach whereby the whole of the watershed can be holistically viewed and managed will be desirable.

Key words: land cover change, water yield, low flows, watershed management, Ethiopia

Introduction

As is the case in many other developing countries, most of the population of Ethiopia lives in rural areas and depends directly on the land for its livelihood. This rural population is currently growing rapidly, and consequently inducing many effects on the resource base. One such effect is a very dynamic land use and land cover. This has been confirmed by empirical studies carried out in different parts of the country (Solomon, 1994; Kebrom and Hedlund, 2000; Gete and Hurni, 2001). A common concern addressed by many of these studies is the resource degradation brought about by the decrease in the area under natural vegetation and its conversion into other types of land use and land cover that are human-managed systems. One of the forms of resource degradation believed to follow from land cover changes is disturbance in stream flow regimes of watersheds. The underlying simple assumption is that land under little vegetative cover is subject to high surface runoff amounts, low infiltration rate and reduced groundwater recharge. The reduced infiltration and groundwater recharge, eventually, leads to lowering of water tables and intermittence of once-perennial streams. However, for the concern to be justified, the assumption must be based on sound empirical evidence.

Empirical studies are deficient in Ethiopia, but others conducted elsewhere in the world have attempted to evaluate effects of changes in land use and land cover on stream flow patterns. For example, Van Lill et al. (1980) reported that afforestation of grassland (with *Eucalyptus grandis* and *Pinus patula*) reduced annual flows at Mokobulaan, Transvaal, South Africa. Bosch and Hewlett (1982) analysed results from 94 experimental catchments located throughout the world and found that annual water yield of catchments increased as forest cover decreased. In their study in Iringa, Tanzania, Loerup and Hansen (1997) reported that low flow amount was larger in catchments under traditional smallholder agriculture than those under indigenous forest cover. Similarly, a study by Smith and Scott (1992) conducted in South Africa showed that low flow was larger in non-forested catchments than forested ones. According to Scott and Smith (1997), afforestation decreased water yield of catchments and reductions in low flows were greater than the reductions in annual flows.

On the other hand, in their study in an upland watershed in Sri Lanka, Elkaduwa and Sakthivadivel (1998) discovered that replacement of natural forests by other agricultural land uses led to decreased base flows and increased surface runoff generation, while the annual water yield remained more or less unchanged. Sandstroem (1995) reported that low flow amount was higher in a catchment under woodland cover than from a catchment under cultivation and grazing uses in a semiarid region of Tanzania. The implication is that the cultivation and grazing uses led to reductions in the low flows. Similarly, Loerup et al. (1998) reported a decrease in the annual runoff in 'most of the six catchments' they studied in rural Zimbabwe with increases in population density and agricultural intensity, implying that the population pressure decreased the runoff of the catchments.

These contrasting research findings suggest that the impacts of land cover changes on water resource systems vary from place to place, depending on site-specific factors. Hence, there is clearly a need for empirical investigations into the problem. As stated by Calder (1998, 2000), the hydrological impacts of land use and land cover changes are still contentious issues and further research is necessary. In Africa, in particular, Newson (1992:166) confirmed, 'there is, as yet, only the thinnest body of empirical knowledge on the hydrological effects of land use and management'.

A study of stream flow patterns with respect to land cover dynamics enables assessment of sustainability of land use systems, because the stream flows are reflections of the ecological state of the entire watershed. The information can also be employed to forecast the likely effects of any potential changes in land cover on water resource systems. Hence, such a study has practical relevance for devising strategies and policies for a sustainable land and water use. Though there is abundant literature on the extent of deforestation and soil erosion in the highlands of Ethiopia, changes in stream flow patterns associated with land cover dynamics are poorly documented. The objective of this paper was, therefore, to examine flow patterns of the Chemoga stream, a headwater of the Blue Nile, with a view to evaluate the effects of land use/ cover dynamics.

Land cover changes in the Chemoga watershed

Site information

The Chemoga watershed is located in the northwestern highlands of Ethiopia, within 10^0 18' N to 10^0 39' N and 37^0 44' E to 37^0 53' E. It covers an area of 364 km^2. The climatic condition is generally humid, with mean annual temperature of 14.5^{0}C and rainfall of 1300 mm. Geologically, the Chemoga watershed is part of the highlands that largely owe their altitude to the uplift of the Arabo-Ethiopian landmass and the subsequent outpouring of basaltic lava flows during the Tertiary period. Thus, the surface geology is of basaltic rocks, which are the parent materials for the overlying soils (Mohr, 1971). The physiography of the watershed reflects its geologic history. The uplift created an elevated landmass and the subsequent lava emission added to the altitude. This landscape has been subjected to geomorphic processes which have significantly reshaped it. Currently, the Chemoga watershed is characterized by diverse topographic conditions. The elevation ranges from 2420 m to nearly 4000 m, and slopes range from nearly flat (< 2%) to very steep (> 55%). A mountainous and highly dissected terrain with steep slopes characterizes the upstream part, and the downstream half is characterized by an undulating topography and gentle slopes.

The soils in the watershed that cover much of the total area can be classified into three types on the basis of their color: dark brown, reddish and grayish (gray to dark). The dark brown soils belong to the Andosols soil associations, the reddish soils belong to the Nitisols and the grayish soils belong to the Fluvisols, according to the FAO/ Unesco (1990) soil classification system. The dark brown soils are at high altitudes with a temperate- and alpine-like climate, and cover a large area in the upstream part of the watershed. Owing to the nature of the agro-climate, only few types of crops (barley, oats and potatoes) are grown in these areas. The reddish soils occur on nearly level to gently undulating land that is well drained. These soils largely occupy the midstream and downstream parts of the watershed. They constitute the most intensively utilized types, on which the subsistence-oriented farmers of the region grow a variety of crops (barley, oats, wheat, potatoes, beans and *tef*). The grayish (gray to dark) soils occur in the floodplains in the downstream reaches of the watershed, where alluvial sediment is deposited every wet season. Because of the regular flooding, these floodplains are not used for crop production. However, they constitute a very important area of livestock grazing, particularly during the dry season, when the good reserves of soil moisture keep the grass green.

The Chemoga watershed is inhabited by a total population of about 40,768, who are engaged in mixed agriculture that is carried on a subsistence scale. Land and livestock are their basic sources of livelihood. Agriculture is rainfed and livestock provide the draught power that is needed for the farming operation. The stream flows of the Chemoga and its small tributaries are the only sources of water for both the human and livestock populations. In some parts of the watershed, the variability in the rainfall and stream flow distributions creates a serious shortage of water during the dry season (field observation).

Dynamics in land cover since the 1950s

Details of land cover dynamics in the Chemoga watershed over the period between 1957 and 1998, which were obtained by interpretation of aerial photos and a multi-spectral Spot image, are given in Woldeamlak (2002). Only a summary is presented here. For clarity, a brief definition of the various land cover types is given in Table 1; and the changes in land cover between 1957 and 1998 are presented in Table 2.

Between 1957 and 1982

By 1957, most of the area was occupied by farmland & settlements (60%), distantly followed by marshland (14%) and grassland/ degraded land (10%). Woodlands and shrublands covered some 7 and 5% of the area of the watershed, respectively. The area coverage of forest was more than 2% of the total, and riverine trees accounted for about 1% of the total area. Between 1957 and 1982, the area under forest, farmland & settlements and marshland increased. The area under forest increased by 19%, and the marshland increased by 15% between 1957 and 1982. The farmland and settlements increased by 13%; which is from 22,000 ha in 1957 to 24,832 ha in 1982. Woodlands, shrublands and grassland/ degraded land areas decreased. The decline was greatest for the grassland/ degraded land areas, which declined by 50% (from 3,508 ha in 1957 to 1,766 ha in 1982). This was followed by woodlands that shrank by 46% (from 2,449 ha in 1957 to 1, 321 ha in 1982). Shrublands decreased by 41% (from 1,860 ha in 1957 to 1,099 ha in 1982); and riverine trees decreased by 40% (from 458 ha in 1957 to 277 ha in 1982).

Table 1. Description of the land use/ cover classes identified in Chemoga watershed, Ethiopia

Land use/cover	Description
Farmland and settlement	Areas used for crop cultivation, both annuals and perennials, and the scattered rural settlements that are closely associated with the cultivated fields. Some trees, mainly eucalypts, which are commonly found around homesteads, were also included in this category.
Forest	Areas covered with dense growth of trees that formed nearly closed canopies (70-100%). This category included plantation forests, mainly eucalypts and junipers, mixed with regenerating indigenous species of trees and bushes.
Woodland	Areas with sparse trees mixed with short bushes, grasses and open areas; less dense than the forest.
Shrubland	Areas covered with shrubs, bushes and small trees, with little useful wood, mixed with some grasses.
Grassland/ degraded land	Grassy areas used for communal grazing, as well as bare land that has very little or no grass cover (exposed rocks) but with the same tone on the air photos.
Riverine trees	Linear areas of trees and shrubs along the stream courses.
Marsh	Areas that are waterlogged and swampy in the wet season, and dry in the dry season. These are very important for grazing during the dry season.
Pond	Fed by rainfall and runoff.

Between 1982 and 1998

The largest proportion of the watershed remained under farmland & settlements between 1982 and 1998 (accounted for 67% of total area in 1998). Areas of grassland/ degraded land, riverine trees and marshland showed a decrease over the same period. The rate of decrease was 30 ha per annum for the grassland/ degraded land (28% decrease), 18 ha per annum for the marshland (5% decrease) and 11 ha per annum for the riverine trees (66% decrease). Areas under forest, woodlands and shrublands increased between 1982 and 1998. The rate of increase was the highest for woodlands (71 ha per annum), and that of forests was a distant second (17 ha per annum). Shrublands increased only slightly (5 ha per annum). A new pond of about 40 ha emerged in the marshland between 1982 and 1998.

Table 2. Land cover changes between 1957 and 1998 in Chemoga watershed, Ethiopia

Land use/cover	Area in 1957 (ha)	Area in 1982 (ha)	Area in 1998 (ha)	Change between 1957 and 1982 (%)	Change between 1982 and 1998 (%)
Forest	873	1041	1321	+19	+27
Woodlands	2449	1321	2457	-46	+86
Shrublands	1860	1099	1186	-41	+8
Farmland & settlements	22,000	24,832	24,246	+13	-2
Grassland/ degraded land	3508	1766	1276	-50	-28
Riverine trees	458	277	94	-40	-66
Marshland	5252	6064	5780	+15	-5
Pond	-	-	40	-	+100
Total	36,400	36,400	36,400	-	-

Over the four decades, the major change in land cover was the increase of the cultivated area at the expense of the open grazing area. The forest cover also showed a persistent, though slight, increase. It increased by more than 50% with a rate of 11 ha per annum. The increased forest cover is attributable to the reforestation and afforestation activities during the *derg* regime, a local initiative that preserved a small area of indigenous trees and forests and the planting of trees by the rural households (Woldeamlak, In press). The contribution of the households' tree planting practices, mainly eucalypts, to the present areal extent of forests is significant. Eucalyptus plantations, therefore, are now an important land cover type in the watershed. The pattern of change of woodlands and shrublands was broadly similar. Both showed a decrease in the first period, and an increase in the second. Between 1957 and 1982, woodlands and shrublands decreased by 46 and 41%, respectively; and between 1982 and 1998, woodlands increased by 86% (a recovery to more than its 1957 coverage) and shrublands increased by 8% (yet less than its 1957 coverage).

Data and methods

Unlike the conventional methods of the paired-catchment approach, which requires a long period of monitoring, and the modelling approach, which is data intensive, the present study was set out to analyse historical stream flow patterns in reference to historical dynamics in the land cover of the study watershed. This methodology is, according to Elkaduwa and Sakthivadivel (1998), a rapid, practical and a good alternative to the paired-catchment and modelling approaches particularly for the tropical regions, where the latter two methods face practical problems (e.g., lack of sufficient data). The stream flow data needed for the study were obtained from the Hydrology Department of the Ministry of Water Resources (MoWR) of Ethiopia, which has kept the records since the last four decades in daily time-step. The stream flow data are derived from staff gauge readings, which are converted into cubic meters per second by using rating curves. The staff gauge readings are taken twice in a day (6:00 AM and 6:00 PM) and the average of the two is registered as the daily flow. According to MoWR (1997), the stream flow data of the Chemoga hydrometric station are of good quality and reliable.

Daily rainfall data were available for a nearby weather station, Debre-Markos ($10^0$20'N, $37^0$40'E and 2411m), which were obtained from the National Meteorological Services Agency of the country. The rainfall data at the Debre-Markos station extended for over four decades; and the annual rainfall data at this station showed a statistically highly significant correlation with the annual stream flow data. This station was, therefore, taken as representative of the average rainfall for the whole of the watershed. The use of a single station to represent the areal rainfall of the watershed is in accord with experience from elsewhere. For instance, Elkaduwa and Sakthivadivel (1998) used rainfall data from a single station in their study of land use impacts on stream flow in a topographically diverse tropical watershed of 379.5 km^2 in Sri Lanka. IWE (1937) showed that 24 representative gauges could estimate areal rainfall to within 2% of that determined by 'a more elaborate method using 225 stations' for the Thames basin, which is 9,981 km^2 in area (IWE, 1937 cited in Shaw, 1983:210). According to Bruce and Clark (1966), for comparison of seasonal precipitation figures with seasonal runoff volumes, stations as few as 'one per 500-750 km^2 usually suffices'. Given the significant correlation between the rainfall data at the Debre-Markos station and the stream flow data, and in view of the above-mentioned literature, the use of this single station as representative of the areal rainfall of the study watershed was justified.

For the purpose of analysis, the stream flow data, which were available in units of volume of water passing the measurement station per unit of time, were first converted into their depth equivalents and expressed in the same unit as with the rainfall data. Both the stream flow and the rainfall data were then organised at the monthly, seasonal and annual time-steps. The methods of data analysis employed include calculation of indices of variations and long-term trends of the stream flow in relation to variations and trends in the rainfall, so as to distinguish the effects of land cover dynamics. The method of moving averages, 5-years span, and the linear regression technique were used for identifying trends of long-term changes. For a better understanding of the hydrologic impacts of land cover dynamics, variations and trends in the extreme high and low flows at the monthly and daily time-steps were analysed separately.

Results

Monthly rainfall and stream flow

Table 3 shows characteristics of long-term monthly rainfall and stream flow amounts. January is the driest month, and August is the wettest. The largest year-to-year variation of the rainfall is in December; and the lowest is in August. As shown by the monthly rainfall distribution, months from October to May constitute the dry season; and the wet season extends from June to

September, with a heavy rainfall concentration in July and August. Rain also occurs between March and May, with a peak in April, but it is very small in amount. The dry season between October and April is locally known as *bega*, the small rains as *belg* and the wet season as *kiremt*.

During the *bega* season, the stream flow of the watershed is only base flow. Stream flow is lowest in February and peaks in August, when most rainfall occurs. The year-to-year variations are highest in March, and lowest in August. The stream flow is low between March and May despite the small rains occurring, because of the long dry season preceding it over which watershed storage gets exhausted and the little rains occurring has to fulfil the evaporation, transpiration and soil moisture storage demands before generating runoff. For further analysis in this study, the *belg* season was considered to be part of the dry season, because the amounts of rainfall and stream flow are small. Moreover, the wet season is rather distinctively constituted by the four months from June to September.

Variations and trends in total annual stream flow

The mean annual rainfall and stream flow, over the period of record, were 1300 mm and 496 mm, respectively (Table 3). The maximum annual rainfall and stream flow amounts were 1.3 and 1.7 times the respective long-term average values; and the minimum amounts were 0.8 and 0.5 times the long-term average values. The period between 1970 and 1984 was generally dry, as reflected by both rainfall and stream flow amounts (Fig. 1). This time span, in fact, corresponds to the major drought experienced in the country. The inter-annual variations of rainfall and stream flow are shown by the respective coefficients of variations (Table 3). It can be seen that the stream flow was generally more variable than the rainfall. Both rainfall and stream flow showed positive skewness, indicating the asymmetric nature of their distributions. The coefficient of kurtosis was negative for the rainfall, but positive for the stream flow. Hence, the rainfall distribution was less peaked while the stream flow distribution was more peaked compared to the normal distribution.

Table 3. Characteristics of monthly and annual rainfall (P) and stream flow (Q) in Chemoga watershed, Ethiopia (1960-1999)

		J	F	M	A	M	J	J	A	S	O	N	D	Annual
P	Mean (mm)	14.4	19.5	45.6	65.2	45.6	161.8	294.3	309.4	219.6	79.4	27.9	17.6	1300.1
	Min. (mm)	0.0	0.0	3.0	3.9	3.0	88.6	164.9	172.6	111.5	0.0	0.0	0.0	1047.1
	Max. (mm)	72.9	74.4	159.6	214.6	159.6	299.9	460.8	441.4	322.1	210.5	121.6	95.5	1689.8
	CV (%)	112.2	95.6	77.9	70.0	77.9	27.2	21.3	18.7	23.15	73.3	116.0	129.9	11.5
Q	Mean (mm)	2.8	2.7	3.1	3.1	5.4	12.6	109.9	206.2	104.4	33.1	7.9	5.1	496.2
	Min. (mm)	0.0	0.2	0.1	0.1	0.1	1.2	25.0	124.7	25.7	9.1	1.4	0.2	272.4
	Max. (mm)	11.1	24.9	37.1	14.2	34.2	66.0	271.6	370.6	221.3	101.1	28.9	25.4	850.4
	CV (%)	73.2	145.0	188.9	104.9	131.1	115.4	47.7	27.1	43.9	83.2	77.5	96.9	28.3

To discern the long-term temporal changes, linear trend curves were fitted to 5-year moving averages of the annual rainfall and stream flow (Fig. 1). These linear regression models show that, over the 40 years, the annual rainfall remained more or less constant, decreasing only slightly at a rate of 0.29 mm per annum. But, the stream flow decreased at 1.7 mm per annum. Temporal changes in the rainfall and stream flow of the watershed differed for the periods between 1960-1982 and 1983-1999. These two periods also corresponded with the available information on land cover changes in the watershed. Hence, the rainfall and stream flow data were analysed for the two periods separately.

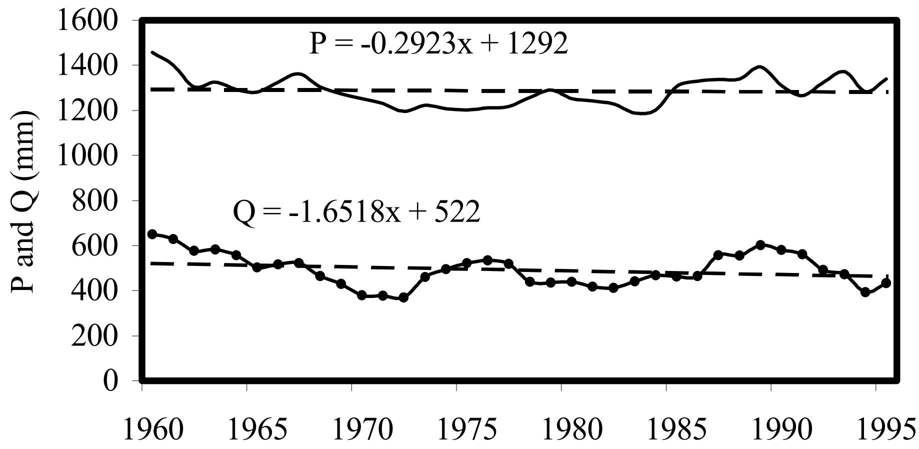


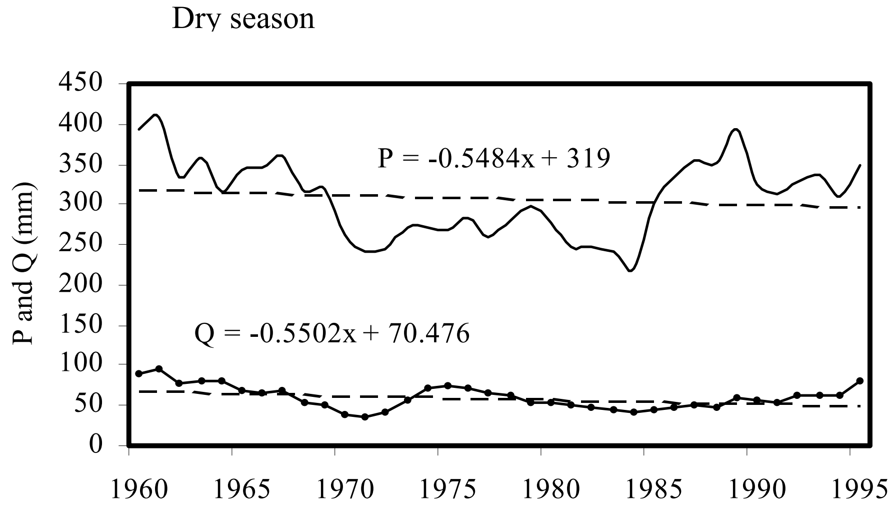
Figure 1. Variations and trends of annual rainfall (P) and stream flow (Q) in Chemoga watershed, Ethiopia (5- year moving averages)

During the 1960-1982 period, both the rainfall and stream flow decreased. The annual rates of decrease were 10.6 mm for the rainfall and 8.3 mm for the stream flow. These annual rates of changes were statistically significant; and the linear trends accounted for 69% of the variation in the rainfall and 34% of the variation in the stream flow. During the 1983-1999 period, the rainfall increased at 7.6 mm per year, but the stream flow continued to decrease at 1.5 mm per year. That is, despite the increased rainfall from 1240 mm to 1370 mm, the stream flow decreased from 510 mm to 480 mm during this period.

Changes in seasonal stream flows

The dry season stream flow (October - May)

The stream flow of the watershed during the dry season decreased from 70 mm in 1960 to 48 mm in 1999, a rate of decrease of 0.6 mm per annum (Fig. 2). The linear trend of decline accounted for 15% of the variation in the stream flow, and it was statistically significant at 0.05 level of probability. But, because of the large inter-annual variations, no discernible trends were found for the corresponding rainfall. There was difference in the magnitudes and directions of temporal changes in the dry season's rainfall and stream flow during the 1960-1982 and 1983-1999 periods.



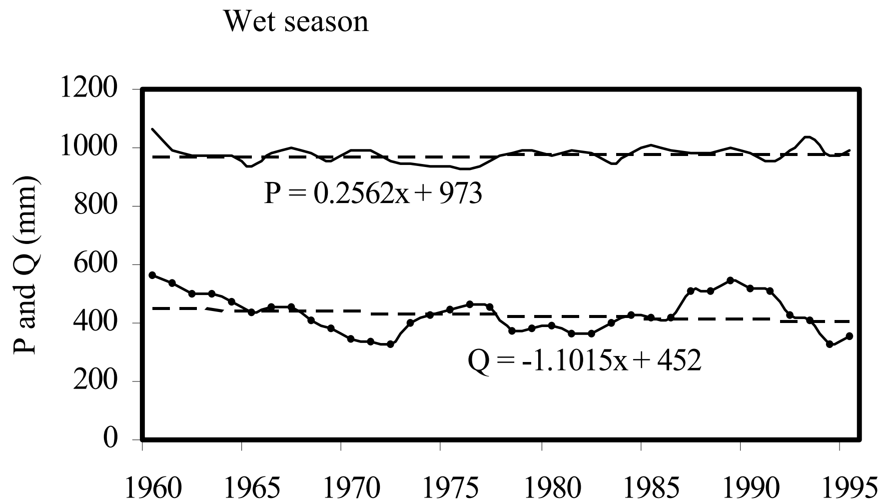


Figure 2. Variations and trends of rainfall (P) and stream flow (Q) during the dry and wet seasons in Chemoga watershed, Ethiopia (5-year moving averages)

During the 1960-1982 period, both the rainfall and stream flow of the dry season followed decreasing trends. The rainfall decreased from 383 mm in 1960 to 213 mm in 1982, a rate of decrease of 7.4 mm per annum; and the stream flow decreased from 80 mm in 1960 to 47 mm in 1982, a rate of decrease of 1.4 mm per annum. The annual rates of changes of both the rainfall and stream flow were statistically significant and explained 70% of the variation in the rainfall and 22% of the variation in the stream flow. During the 1983-1999 period, both rainfall and stream flow showed trends of increase. The rainfall increased from 278 mm in 1983 to 380 mm in 1999, a rate of increase of 5.9 mm per annum; and the stream flow increased from 38 mm in 1983 to 79 mm in 1999, a rate of increase of 2.4 mm per annum. The linear trends accounted for 25% of the variation in the rainfall and 84% of the variation in the stream flow, which was highly significant.

The wet season stream flow (June - September)

During the wet season, rainfall is at its peak, and a large amount of the stream flow is generated from surface runoff. Trend curve fitted to the period of record (1960 to 1999), based on 5- year moving averages, showed that the wet season's rainfall remained around 970 to 980 mm and the stream flow fluctuated between 400 and 450 mm, both of which were without statistically discernible trends (Fig 2). During the 1960-1982 period, the wet season's rainfall and stream flow followed decreasing trends. The rainfall decreased from 1003 mm in 1960 to 929 mm in 1982, an annual decrease of 3.2 mm; and the stream flow decreased from 505 mm in 1960 to 345 mm in 1982, an annual decrease of 6.9 mm. The annual rates of changes of both the rainfall and stream flow were statistically significant and explained 33% of the variation in the rainfall and 37% of the variation in the stream flow. During the 1983-1999 period, both rainfall and stream flow of the wet season showed statistically insignificant changes.

Changes in extreme flows

Extreme monthly flows

The long-term average monthly stream flow is lowest in February and highest in August (Table 3). The temporal changes in the stream flows during these two months, which can well represent the extreme conditions of water availability in the watershed, are depicted in Figure 3, along with the corresponding rainfalls. Over the period of record, the monthly rainfall and stream flow amounts during February showed declining trends. The rainfall decreased from 27 mm in 1960 to 12 mm in 1999 (55% decrease), and the stream flow decreased from 5 mm in 1960 to 0.3 mm in 1999 (94% decrease). The linear trend of decrease accounted for 26% of the variation in the rainfall and 49% of the variation in the stream flow, both of which were statistically highly significant. The monthly stream flow showed a declining trend for August, as well. It decreased from 217 mm in 1960 to 195 mm in 1999, a rate of decrease of 0.54 mm per annum. However, the annual rate of change (decrease) was insignificant statistically. On the other hand, the monthly rainfall of August showed an increasing trend. It increased from 285 mm in 1960 to 328 mm in 1999, an annual increase of 1.1 mm. The annual rate of change (increase) of the rainfall was statistically significant and the linear trend accounted for 19% of the variation.

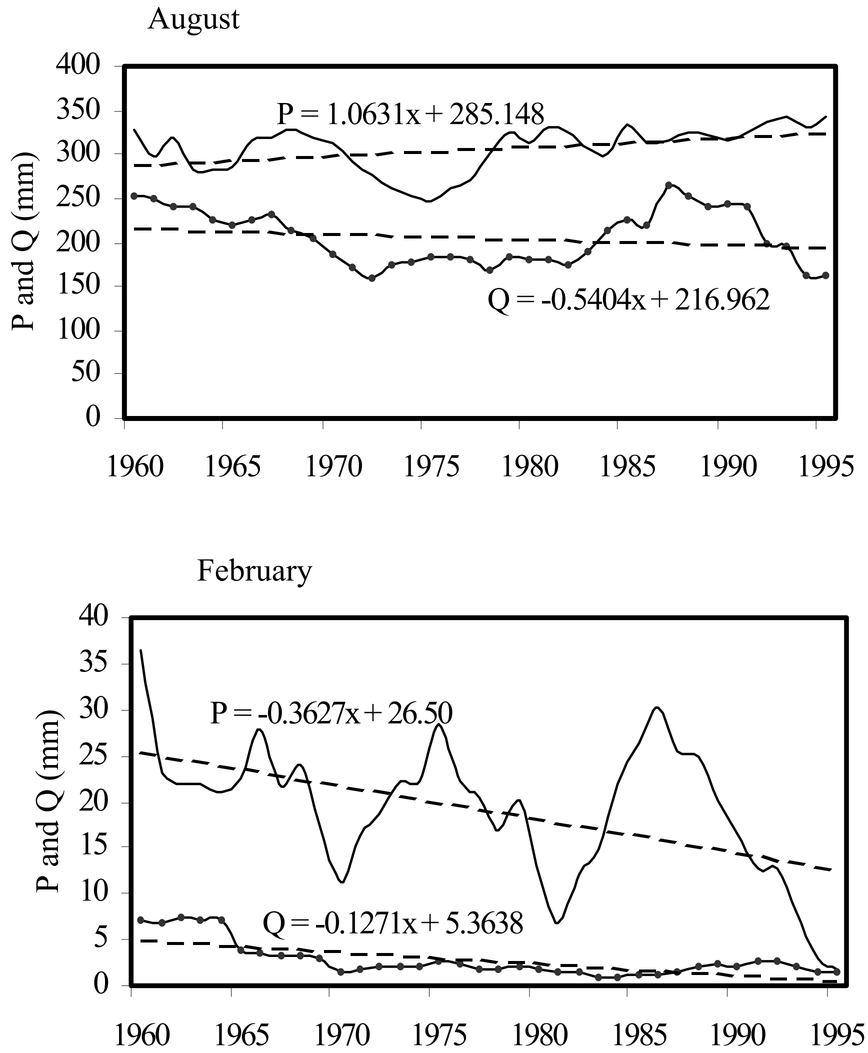


Figure 3. Long-term average monthly rainfall (P) and stream flow (Q) during February (extreme low flow) and August (extreme high flow)

The decrease of the monthly stream flow was more significant in February compared to that of August. This can be clearly seen from the temporal changes in the ratio of the two quantities (Fig. 4). The ratio of February stream flow (the minimum) to August stream flow (the maximum) (Qmin/Qmax ratio) decreased from 2.24% by the beginning of the 1960s to 0.41% by the end of the 1990s. The decrease of the ratio was large during 1960-1989; then it slightly increased during 1990-1994; and after 1994, it began to decline again. As the coefficient of determination (R^2) value indicated, the trend line (of decrease) accounted for 49% of the variation in the ratio, and it was statistically highly significant. The stream flow has, therefore, dwindled more during months that are already dry.

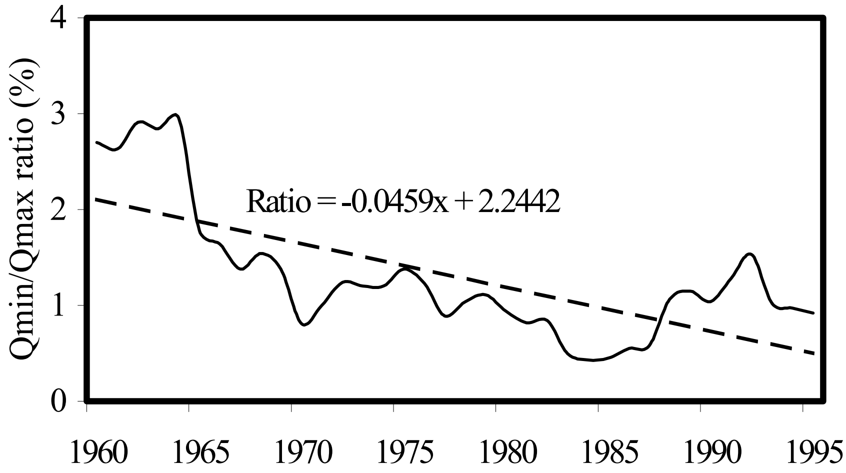
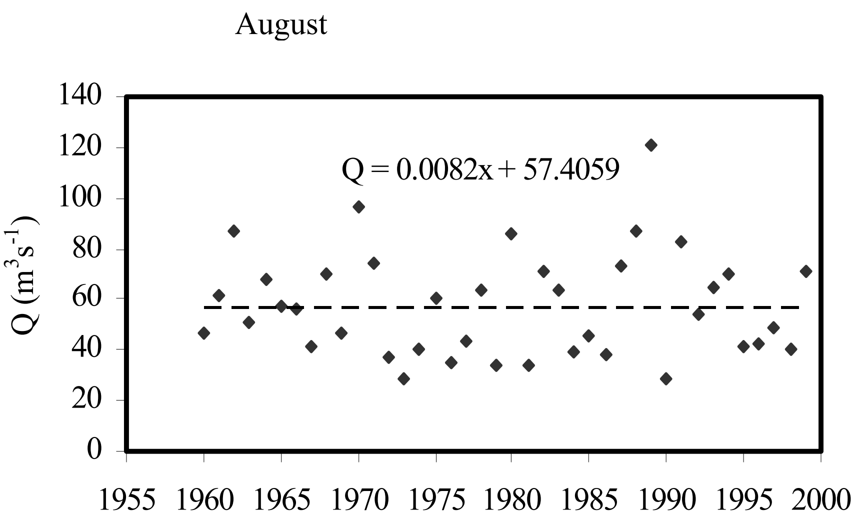


Figure 4. Ratio of minimum (February) to maximum (August) stream flow (%) in Chemoga watershed, Ethiopia (5- year moving averages)

Extreme daily flows

In order to scrutinise any changes in the extreme flows at the daily time-step, we analysed variations and trends of the maximum daily stream flows of the three wettest months (July, August and September) and the minimum daily stream flows of the three driest months (December, January and February). The maximum daily stream flow refers to the highest value recorded in a single day in each year during each of the three months; and similarly, the minimum daily stream flow refer to the lowest value recorded in a single day in each year during each of the three months. These two series represent conditions of very high daily flows and extreme water scarcity in the watershed. The maximum flows, however, do not necessarily represent peak floods as the measurements were taken at fixed time intervals (twice in a day) regardless of discharge levels. The long-term changes in the maximum daily flows of August and the minimum daily flows of February, the two months representing the extreme conditions, are shown in Figure 5.

Over the period 1960 to 1999, the maximum daily stream flow ranged from 16 to 112 m^3s^{-1} in July, from 28 to 121 m^3s^{-1} in August and from 8 to 94 m^3s^{-1} in September. These maxima showed large inter-annual variations in each of the three months. The coefficients of variations were 51% for July, 36% for August and 54% for September. As shown by the bivariate linear regression equations, the maximum series followed very slight increasing trends during July and August, but a decreasing trend during September. However, the respective annual rates of increase (during July and August) and decrease (during September) were very low and statistically non-significant. Hence, it can be concluded that there had been no discernible trend in the magnitudes of the daily maximum stream flows over the four decades of observation.



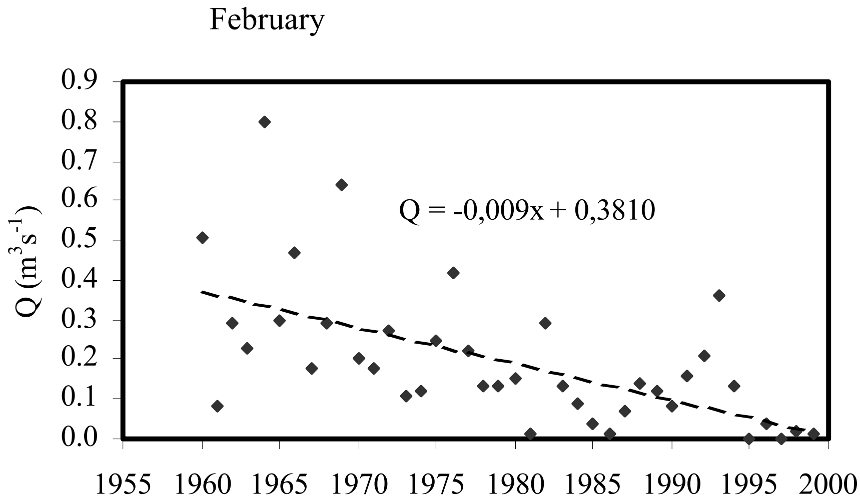


Figure 5. The maximum (August) and minimum (February) daily stream flows (Q) representing the wettest (August) and the driest (February) months in Chemoga watershed, Ethiopia

The minimum daily stream flows recorded during the three driest months (December to February), which represent the period of critical water scarcity in the watershed, had been below 1.0 m^3s^{-1} during almost all the 40 years of observation. Indeed, in the month of February, the minimum daily runoff had reached the zero mark five times out of the forty observations (13% of the total). The year-to-year fluctuations had also been very significant. The coefficients of variations were 70% for December, 66% for January and 90% for February. More importantly, the bivariate linear regression equations reveal that the minimum series followed trends of decline over the four decades of record. It declined from 0.6 m^3s^{-1} in 1960 to 0.2 m^3s^{-1} in 1999 in December, from 0.4 m^3s^{-1} in 1960 to 0.1 m^3s^{-1} in 1999 in January and from 0.4 m^3s^{-1} in 1960 to 0.02 m^3s^{-1} in 1999 in February. As the coefficient of determination (R^2) values indicated, the linear trend of decline accounted for 23% of the variation in the minimum series during December, 26% of the variation during January and 35% of the variation during February. The declining trends were statistically significant at < 0.01 probability level for all the three months.

Discussion and conclusions

In the Chemoga watershed, land cover/ use changes have occurred since the 1950s. The major change was the increase of the cultivated area at the expense of the open grazing area. The forest cover also showed a slight increase and this was mainly due to the increase of areas under eucalypt plantations. This dynamics in land cover/ use has affected the stream flow of the watershed. Over the period between 1960 and 1999, the total annual stream flow decreased at a rate of 1.7 mm per annum, whereas the annual rainfall decreased only at a rate of 0.29 mm per annum. The decrease in the stream flow was caused by the slight decrease in the rainfall, increased transpiration losses due to the increased tree cover and a decreased contribution from the base flow, as revealed by the analysis of extreme low flows. Both the increased transpiration losses and the decline in base flow are associated with changes in the land cover of the watershed and/ or watershed degradation.

The increased area under eucalypt plantations is a major contribution to increased transpiration. Studies conducted elsewhere have shown that eucalypt plantations can cause drastic reductions in stream flows. For instance, afforestation of grassland with *Eucalyptus grandis* in the Mokobulaan experimental catchments, South Africa, led to a statistically significant decrease in stream flow only after the third year of planting and a complete drying up of the stream after the ninth year (Scott and Lesh, 1997). Moreover, it took five years after complete clear-felling of the eucalypts at 16 years of age for the stream flow to return to its previous level, which was attributed to a very deep exhaustion of soil moisture and groundwater aquifer by the trees (Scott and Lesh, 1997). Similarly, in their study in southern China, Zhou et al. (2002) found that water table level in a catchment planted with eucalypts (*Eucalyptus exserta*) was 80 cm lower than that under a bare catchment while it was only 30 cm lower in another catchment under mixed forest, showing that eucalypts ‘absorb water from deeper in the profile’. A study in northern Australia by Hutley et al. (2000) also showed that water use by eucalypts was not only high but also varied very little between wet and dry seasons despite a very high seasonality in the rainfall distribution, indicating that the trees extracted much from the soil moisture and groundwater during the dry season, which could explain the decrease in base flow in the Chemoga watershed during the dry season.

Differences were observed in the temporal changes in the stream flow of the watershed for the periods between 1960-1982 and 1983-1999. During the first period (1960-1982), both the rainfall and stream flow showed a statistically significant decrease; but the rate of decrease of the stream flow was less than that of the rainfall. Given the decreased contribution from the base flow (as revealed by the low flow analysis), the lower rate of decrease of the stream flow as compared to the rainfall confirms that surface runoff generation had been increasing. Increased surface runoff can be explained by the increased area under farmland and settlements, which had increased by 13% between 1957 and 1982, at the expense of grazing lands. Over the same period, there was a substantial decrease in the area coverage of woodlands, shrublands and riverine trees. The decrease in the area of riverine trees was particularly drastic, and much of it was lost to cultivation. During the second period (1983-1999), the rainfall increased from 1240 mm to 1370 mm, but the stream flow continued to decrease from 510 mm to 480 mm. The decrease in the stream flow was most likely a result of the decreased contribution from the base flow due to increased transpiration losses caused by the slightly increased forest cover, particularly eucalypt plantations, in the watershed.

The impacts of changes in land cover and/ or watershed degradation on the catchment hydrology were more evident in the stream flow regimes; i.e., the intra-annual distribution of the stream flow. During the 1960-1982 period, the dry season stream flow showed a declining trend due to the decreasing rainfall and a declining contribution from the base flow. The rate of decrease of the stream flow was, however, less significant compared to that of the rainfall. This was due to an increased runoff to rainfall ratio during the period of small rains (higher surface runoff) between March and May. The increase in surface runoff can be expected from the changes in the land cover/ use in the watershed. Between 1957 and 1982, there was a considerable increase in areas under farmland and settlement uses; and decreases in areas under woodlands, shrublands and riverine trees. The decrease in the area under vegetative covers implies increased surface runoff generation. In their recent study in the Chemoga watershed, Woldeamlak and Sterk (In press) observed that large volume of surface runoff occurs during storm events.

During the 1983-1999 period, the dry season stream flow increased in accord with the increased rainfall. But, the rate of increase in the stream flow was less than that of the rainfall, signifying a decreased runoff to rainfall ratio. The decrease in the runoff to rainfall ratio is to be explained by increased water use by the increased vegetative covers in the watershed, specifically eucalypt plantations, which occurred between 1982 and 1998. The wet season stream flow showed a statistically significant decrease during the 1960-1982 period, which was caused by the decrease of the rainfall as well as the decreased contribution from the base flow. During the 1983-1999 period, the wet season rainfall and stream flow did not show any significant trend. The effect of changes in the land cover and/ or watershed degradation was, therefore, more pronounced in the case of the dry season flow. Scott and Lesch (1997) reported a similar finding- that of greater declines in the dry season flow as compared to the wet season flow following afforestation of a watershed with eucalypts.

Analysis of temporal changes in the minimum and maximum flows at the monthly and daily time-steps unravelled the effects of land cover changes and/ or watershed degradation even more clearly. During the month of lowest long-term average stream flow, February, the monthly rainfall decreased from 27 mm in 1960 to 12 mm in 1999 (55% decrease), and the stream flow decreased from 5 mm in 1960 to 0.3 mm in 1999 (94% decrease), a more significant decline and suggesting that the decrease in the rainfall was not the only cause. Moreover, the stream flow during February is basically base flow that is affected not only by the rainfall of the month but also by the rainfall in the other months of the year. During August, the month of highest stream flow, the rainfall showed an increase, but the stream flow showed a slight decrease. The decline in the stream flow while the rainfall increased was caused by the decreased contribution from the base flow. Similarly, analysis of the minimum daily flows recorded during the three driest months (December to February) showed declining trends, the annual rates of changes being statistically highly significant. But, the maximum daily flows of the three wettest months (July to September) did not reveal statistically significant discernible trends over the four decades of observation.

The observed decreases in the minimum flows are significant particularly when viewed with reference to the size of the watershed. Generally, effects of land cover changes on stream flows decrease as the size of the watershed increases, to become barely observable as the size becomes 1000 km^2 and above (Kiersch, 2000). In other words, much more significant decreases of water availability must have occurred at smaller spatial scales within the Chemoga watershed. The decrease in the stream flow, particularly during the dry season, has critical implications not only on the quantity but also the quality of available water for domestic uses as well as for watering livestock. It is important to note that the local people are entirely dependent on the surface waters of the Chemoga stream and its small tributaries for water for the various uses.

In summary, the observed adverse changes in the hydrology of the watershed have apparently resulted from expansion of cultivation into steeplands, degradation of grazing lands and the increased area under eucalypt plantations, which led to reduced infiltration rates, decreased groundwater recharge, enhanced surface runoff production and increased transpiration losses. Sustaining the water resource and maintaining a balanced dry season stream flow hence requires a set of measures aimed at reducing magnitudes of surface runoff generation and increasing groundwater recharge in the watershed. The measures should include soil and water conservation works in cultivated and grazing lands, reducing livestock pressure on grazing lands, limiting further expansion of areas under eucalypt plantations and providing farmers with water-efficient tree species. Generally, integrated watershed management (IWM) approach whereby the whole of the watershed can be holistically viewed and managed in an integrated manner is desirable.

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Chapter 5

Assessment of soil erosion in cultivated fields using a survey methodology for rills in the Chemoga watershed, Ethiopia

Woldeamlak Bewket and Geert Sterk

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Assessment of soil erosion in cultivated fields using a survey methodology for rills in the Chemoga watershed, Ethiopia

Abstract

Soil erosion by water is recognized to be a critical economic problem in highland Ethiopia. However, nearly all the available information about its severity and economic costs are extrapolated from plot and micro-watershed level studies which are too few in number to represent the diverse environments of the country. Moreover, plot and watershed level studies do not show actual soil losses from cultivated fields, while understanding the magnitude of soil loss at the field scale is important for practical conservation planning. This paper reports results of field-scale soil erosion assessment that employed a survey methodology for rills and was conducted over two wet seasons (the years 2000 & 2001) at two sites, Kechemo and Erene, located in the upstream and downstream reaches of the Chemoga watershed, northwestern highland Ethiopia. The two wet seasons average rill erosion magnitudes were 13.5 Mg ha^{-1} in the Kechemo and 61 Mg ha^{-1} in the Erene. Assuming that interrill erosion contributes 30%, actual soil losses were around 18 Mg ha^{-1} in the Kechemo and 79 Mg ha^{-1} in the Erene. These estimates, which are well in agreement with results obtained by measurements in a nearby experimental micro-watershed, reveal that soil erosion is a threat to agricultural production in the study area and conservation measures are needed. Soil erosion showed significant spatial (between and within the two sites) and temporal variations. Hence, soil and water conservation (SWC) measures that fit well into local-scale circumstances will be realistic and acceptable to the farmers. Additionally, the problem of soil erosion should be tackled in the watershed context, because there is a strong physical interdependence between upstream and downstream areas. Finally, the study confirms that the rill survey approach gives good semi-quantitative information on soil erosion in real life situations of diverse farming and land use practices in a fast and inexpensive way; and it is commendable for practical conservation-oriented soil erosion assessment purposes.

Key words: erosion survey, rills, spatial and temporal variations, soil conservation, Ethiopia

Introduction

Soil erosion is presently a global environmental crisis that is severely affecting global food security (Pimentel et al., 1993; Pimentel et al., 1995; Lal, 2001). Although many countries of the world suffer from the problem of accelerated soil erosion, the developing countries suffer more because of the inability of their farming populations to replace lost soils and nutrients (Erenstein, 1999). In Ethiopia, one of the least developed countries of the world, accelerated soil erosion by water constitutes a severe threat to the national economy (Sutcliffe, 1993; Hurni, 1993). As estimated by Hurni (1993), soil loss due to water erosion is about 1493 million Mg per annum. Of this, nearly half is estimated to come from cultivated fields, which account for only about 13% of the country's total area. The estimated rate of soil loss in the cultivated fields is 42 Mg ha^{-1}yr^{-1}, or 4 mm of soil depth per annum, which by all measures exceeds the rate of soil formation. With this rate of loss, much of the slopes of the highlands, where there is only a thin soil layer, will be totally stripped of the soil mantle in less than two centuries.

A study by FAO (1986) estimated an even higher rate of soil loss: 2 billion Mg yr^{-1} in the country as a whole and around 100 Mg $ha^{-1}yr^{-1}$ from cultivated fields. According to this study, some 50% of the highlands was already 'significantly eroded', and erosion was causing declines in land productivity at the rate of 2.2% per annum. The study also predicted that erosion would have reduced per capita incomes of the highlands population by 30% by the year 2010. On the other hand, around 85% of the 64 million Ethiopians derive livelihood directly from the land resource; and this population is currently growing at the rate of about 2.7% per annum, requiring food production increases of at least the same rate (Sonneveld, 2002).

The reported estimates of soil loss in the country are certainly worrisome. However, nearly all the available information about the magnitudes, severity and economic costs of soil erosion are extrapolated from plot and micro-watershed level studies which are too few in number to represent the diverse environments of the country. Moreover, plot and watershed level studies have their own limitations. Strictly speaking, plot level data indicate only the magnitude of soil loss at that particular area which is confined and excluded from interaction with its surroundings. Deposition, which is the other important process in the erosion-sedimentation continuum at larger spatial scales, is almost completely excluded by the plot level measurements. Generally, extrapolating results from the researcher-manipulated plots to larger spatial scales can be misleading because erosion shows extreme spatial variation with variations in rainfall energy, gradient and length of slopes, inherent soil characteristics affecting its erodibility and land use and land management practices. The variability in soil erosion is very large even between replicated plots, which is a result of natural variability and measurement variability (Nearing et al., 1999).

On the other hand, watershed level data are spatially aggregated, in the sense that only sediment yields at a point outlet are measured and how much of it comes from which part of the watershed remains unknown. In other words, watershed level data do not indicate actual soil losses from cultivated fields, which are the units of land use and management by the farmers, to be readily used as inputs for planning of soil and water conservation (SWC) intervention. Thus, as Herweg (1996) has succinctly put it; '…there is a measurement gap between plot and catchment level', for SWC planning purposes. For practical conservation planning purposes, understanding the magnitude of soil loss at the field scale, or the spatial distribution of the problem, is very important. It has immediate significance to development agents and field technicians for a targeted and cost-effective conservation intervention by identifying most vulnerable landscapes and setting of priorities.

Rill erosion constitutes one of the mechanisms of soil loss by water on agricultural land. It is probably the most important form because in addition to being an erosion feature in itself, rills serve the purpose of transporting materials supplied by the interrill (splash) erosion. Hence, assessment of soil loss by surveying rill erosion gives a good understanding of the process of land degradation due to erosion by water. Rill erosion survey is a semi-quantitative method for assessing the extent of erosion damage under field conditions, without involving expensive instrumentation, long lead times and/or sophisticated modelling (Herweg, 1996). It is a more conservation-oriented method of soil erosion assessment than the plot and watershed level studies (Herweg, 1996). Some researchers also argued that good field surveys of erosion produce results fairly comparable with test plot derived data (Govers, 1991; Evans, 1993). According to Herweg (1996), results from erosion survey are within 15% accuracy for careful measurements.

Obviously, however, being a semi-quantitative and qualitative assessment, survey results cannot be taken as accurate estimations of soil loss. But, the low cost and the ease with which it can be applied under natural conditions at times compensate for the precision and the high cost test plot and watershed level measurements command. Generally, erosion survey is currently accepted as a good alternative approach to soil erosion research for it has multiple advantages (fastest, cheapest and under actual on-farm situations) (Turkelboom and Trébuil, 1998). Vandaele and Poesen (1995) also underline the fact that measuring volumes of erosion features can be done quickly and with a satisfactory precision (they measured rills and ephemeral gullies in their study). Turkelboom and Trébuil (1998) recommended more studies to be carried out using the survey approach for improving the methodology and to use it for practical conservation planning purposes. The objectives of this study were to: i. assess the magnitude of soil erosion at the scale of cultivated fields by using a survey methodology for rills in a typical watershed (the Chemoga watershed) in the northwestern highland Ethiopia; and ii. evaluate the significance of the rill survey methodology as an alternative approach to soil erosion research.

Materials and methods

Site description

The study was undertaken in two micro-watersheds, namely Kechemo and Erene, in the Chemoga watershed, northwestern highlands of Ethiopia. Kechemo is in the upstream part and Erene is in the downstream part of the watershed (Fig. 1). Altitude ranges from 2,800 to 2,900m in the Kechemo and from 2,450 to 2,500m in the Erene. Kechemo is situated in the part of Chemoga where the topography is characterized by a mountainous and highly dissected terrain with steep slopes. Erene is in the part of the watershed where the landscape is characterized by undulating topography and gentle slopes.

Both sites are characterized by a humid climatic condition. Average annual rainfall is about 1300 mm in the Erene (measured at Debre-Markos ~5 km from Erene), and about 1500 mm in the Kechemo (measured at Rob-Gebeya ~3 km from Kechemo). Mean annual temperature is 14.5^0C in the Erene, and given the higher altitude in the Kechemo, average annual temperature must be lower there, but no records are available. The difference in the rainfall amount between the two sites is a result of the difference in altitude. Also, even though no measurements were taken, it was observed in the field that the rainfall was generally more intense in the Erene than in the Kechemo. In terms of temporal distribution, which has important implications on soil erosion, the rainfall is unimodal in both of the sites with the wet season extending from June to September with a peak in July and August. The time of start of the rains is the end of the long dry season over which all cultivated fields have stayed as communal grazing grounds and the soil has been exposed to the vigorous sun. This means that the soil is barely covered by the beginning of the rainy season, making it highly vulnerable to water erosion.

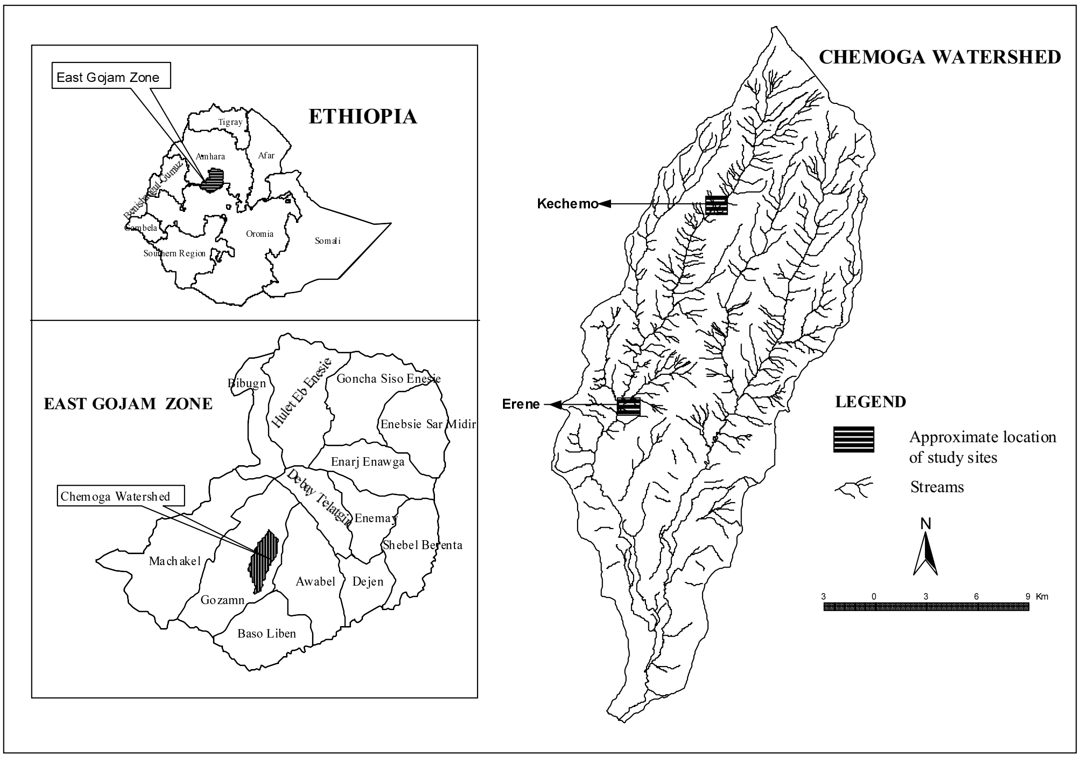

Figure 1. Location map of the study sites in the Chemoga watershed, Ethiopia

There is difference between the two sites in terms of the types of soils. In Kechemo, the main soil types are Andosols (FAO/Unesco, 1990), which have developed from the volcanic ash deposit and cover a large area in the upstream part of the Chemoga watershed. Andosols are universally known for their low bulk density (BD) (generally < 0.85 Mg m^{-3}) and good natural fertility, especially where the reaction of the ash from which it is formed is basic (Fitzpatrick, 1986). In Erene, the soils are reddish in colour and belong to the Nitisols soil associations. They are derived from complete decomposition of the volcanic lava flows by deep tropical weathering in situ. These soils largely occupy the midstream and downstream parts of the Chemoga watershed. Results of analysis of topsoil (0-15 cm) samples of these two soil types taken from cultivated fields are shown in Table 1.

Table 1. Soil properties of the two soil types in Chemoga watershed, Ethiopia

Soil properties	Andosols	Nitisols
Sand (g kg^{-1})	410	370
Silt (g kg^{-1})	440	290
Clay (g kg^{-1})	150	340
Bulk density (Mg m^{-3})	0.6	1.1
Soil organic matter (g kg^{-1})	229	9

Farming system

The farming system in the area is a typical mixed crop-livestock system of the highlands of the country, where livestock provide the draught power needed for the farming operation and a good part of crop residues are fed to livestock. The main types of crops cultivated are barley (*Hordeum vulgare*), oats (*Avena sativa*), wheat (*Triticum vulgare*) and *tef* (*Eragrostis tef*) in the Erene, while in the Kechemo only barley, oats and wheat are grown. *Tef* is an annual cereal crop (belonging to the grass family) which has sparse crop canopies and provides little cover to the soil against erosion. Furthermore, *tef* has very fine seeds that require repeated plowing of fields and preparation of fine seedbeds, which increases the vulnerability of the soil to erosion. During the period of this study (years 2000 & 2001), oats was the dominant crop type in terms of area coverage in both sites. *Tef* was the least in area coverage in both of the two years of observation. Apart from *tef*, the crops have very similar canopy characteristics and cropping calendars (Table 2). Hence, they have similar effects on the erosion process. According to Hurni (1985a), the annual average crop cover factor (C-factor) of the Universal Soil Loss Equation (USLE) is 0.20 for barley, oats and wheat. *Tef* has a C-factor value of 0.25.

Table 2. Cropping calendars for the different crops cultivated in Chemoga watershed, Ethiopia

Crop type	Plowing	Sowing	Weeding	Harvesting
Barley	April – June	June	September	November – January
Oats	April – May/June	May/June	August – September	November – December
Wheat	January – June/July	June/July	July – August	November – January
Tef	January – June/July	June/July	August – October	December – January

The traditional oxen-drawn plough is used for plowing the fields. For sowing barley and oats, plowing of the fields commenced with the first rains; and for wheat and *tef*, plowing of the fields started before the first rains. Plowing was done repeatedly before sowing because the farmers believe that it controls weeds, and crop yields will be better. The frequency of plowing varied with crop types. The *tef* fields were plowed 5 to 7 times, whereas for the other crops the fields were plowed only 3 to 4 times. The plowing created a very rough surface, which provided a large storage space for the rainwater, thereby contributing to protecting the soil from erosion. However, the roughness decreased over time mainly due to raindrop and surface runoff impacts as the amount of the rain increased. The only SWC measures applied by the farmers in both of the sites were traditional ditches known locally as *feses,* which were meant for safe disposal of surface runoff. Generally, the differences between the two sites and the two years of monitoring in terms of land use and management practices were negligible.

The rill surveying procedure

In each of the two sites, fifteen representative fields were selected for the rill erosion survey. The total area of the 15 fields was 27,800m^2 in Kechemo and it was 46,400m^2 in Erene. The total area of the 30 fields was thus 7.42 ha. The topographic position of the fields was such that they represent the cultivated slopes of the respective micro-watersheds. Hence, the fields selected in the Kechemo were generally on steeper slopes compared to those in the Erene. In Kechemo, the selected fields were in the slope angle range of 12 to 22%; and in the Erene, they were in the slope angle range of 6 to 10%. Based on their relative topographic positions, the surveyed fields were classified into three categories: upslope, midslope and downslope fields. The distribution of the fields by the relative slope positions is shown in Table 3. In the Erene, of the total area surveyed, 25% was in the upslope position, 41% in the midslope position and 34% in the downslope position. In the Kechemo, 29% of the total area surveyed was in the upslope position, 46% in the midslope position and 25% in the downslope position. More midslope fields were selected because they represented the slope angle of much of the cultivated fields in the respective study sites. It should also be noted that the upslope fields themselves do not have their upslope portions at water divides, and no effort was made to preclude inflow of surface runoff into these fields because our objective was to assess the magnitude of soil erosion in most commonly cultivated types of slopes in the area under the existing land use and management practices by the farmers. All of the surveyed fields were linear in slope shape.

Table 3. The topographic distribution of 30 surveyed fields at two sites in Chemoga watershed, Ethiopia

	Erene		Kechemo	
Relative position	No. of fields	Total area of fields (m^2)	No. of fields	Total area of fields (m^2)
Upslope	4	11,408	5	7,973
Midslope	6	19,069	6	12,829
Downslope	5	15,923	4	7,018

Each field was intensively monitored for rill erosion over two wet seasons, between June and August, of the years 2000 and 2001. The survey involved repeated visits to the fields. Once the emergence of rills was clearly noticed, which happened to be after the crops were sown, measurements were taken. Each rill was carefully measured for its dimensions of length, width and depth. The length of a rill was measured from its starting point up to the place where sedimentation occurred. In cases of rills that came laterally and merged with a main rill, the length was measured from its starting point to the confluence with the main rill. The width of a rill varied across its depth and length. Depending on the depths and lengths; therefore, widths were measured at two or three depths at a point and at several points along the length. Likewise, depth measurements were taken at two or three sites at a point and at several points along the length. These measurements allowed determination of rill volumes, which in turn, allowed estimating of magnitudes and rates of soil erosion for the fields with an acceptable margin of error. In each field, maximum development of rills, both in number and dimensions, was attained after the middle of the wet season (second to third weeks of August). This maximum value is analysed in this paper as it represented the total soil loss due to rills.

During the survey, in-field observations of the presence of surface runoff entering into the fields from areas in the upslope direction, rill network patterns and occurrence of deposition within fields were made. Daily rainfall data were obtained from the two meteorological stations of Rob-Gebeya and Debre-Markos, and these were used to examine the relationships between the temporal distribution of rainfall amount and eroded soil volume due to rills. Since the two weather stations are quite closely located to the respective research sites (Debre-Markos station is

~ 5 km from Erene and Rob-Gebeya station is ~3 km from Kechemo), on-site rainfall measurements were not undertaken. It was recognized that the estimated soil losses are only best approximations of erosion due to the rills, and they exclude soil loss by the interrill erosion processes. Additionally, no attempt was made to measure the damage caused by siltation of eroded materials, as the more important process in the monitored cultivated fields was erosion.

Data analysis

The quantitative data analysis involved calculation of eroded soil volumes, rill densities and areas of actual damage from the measured length, width and depth dimensions of the rills. To determine the eroded soil volume, each rill was divided into homogenous segments for which average depth and width values were determined and its length measured. The product of the depth, width and length parameters gave the rill volumes, which is equivalent to the volume of soil lost due to the rills. The total volume of soil lost was obtained simply by summing the volumes of all homogenous rill segments. The eroded soil volume was also expressed in terms of weight of eroded soil by multiplying the calculated volume by the measured bulk density of the soils at each of the two sites. The total soil loss was converted into per unit ha of land, to enhance understanding. The area of actual damage, the surface area covered by the rills themselves, was obtained from the product of length and width dimensions of each homogenous rill segment. The rill density at each of the two sites was calculated by dividing the total rill lengths, which were obtained by summing up the length measurements of all the rills, by the total area of the surveyed fields. The rill densities were also converted into per unit ha of land.

By using the calculated rill volumes and areas of actual damage, the temporal and spatial variations of soil erosion were analysed. The temporal variations, which were both inter-seasonal and intra-seasonal, were examined with reference to the temporal distribution of rainfall amount. To inspect the inter-seasonal variation, total soil losses were compared with total rainfall amounts that occurred over the five months of May to September in the study areas during the two years of monitoring. To assess the intra-seasonal variation, the relationships between cumulative eroded soil volumes and ten-daily cumulative rainfall amounts were examined for each of the two years of observation. The spatial variation of rill erosion was analysed by assessing the distribution of the eroded soil volumes and areas of actual damage across the surveyed fields in reference to their relative topographic positions; i.e., upslope, midslope and downslope. The study did not employ advanced statistical techniques because it was based on survey data, which cannot be taken as accurate measurements of soil loss. Herweg (1996) also suggested that advanced statistical methods should not be employed to analyse rill survey data. The qualitative data generated through the in-field observations were used to substantiate and augment findings from the quantitative rill survey data.

Results and discussion

Magnitudes of rill erosion

Table 4 shows total length of rills, eroded soil volume and area damaged by the rills in the surveyed fields of the two sites studied. The total number of the rills was 47 in 2000 and 41 in 2001 in the Erene, and 101 in 2000 and 154 in 2001 in the Kechemo. Rills were formed in all of the 15 surveyed fields in both years of monitoring in the Erene. In the Kechemo, rills were formed only in 13 of the 15 fields in the first year, but in all the 15 fields in the second. The total lengths of the rills represented rill densities of 566 m ha^{-1} in the Kechemo and 351 m ha^{-1} in the Erene in the first year; and 864 m ha^{-1} in the Kechemo and 328 m ha^{-1} in the Erene in the second year. The general pattern of the rills was dendritic in the Kechemo and parallel in the Erene. The total volume of all the rills was ~ 20 m^3 ha^{-1} in 2000 and ~ 25 m^3 ha^{-1} in 2001 in the Kechemo. This is equivalent to 12 Mg ha^{-1} and 15 Mg ha^{-1} of soil loss in the respective years given the soil bulk density of 0.6 Mg m^{-3}. In the Erene, the total volume of all the rills was ~59 m^3 ha^{-1} in the year 2000 and ~52 m^3 ha^{-1} in the year 2001. This is equivalent to 65 Mg ha^{-1} and 57 Mg ha^{-1} of soil loss in the respective years given the soil bulk density of 1.1 Mg m^{-3}. The average soil losses due to rills for the two years of monitoring were 13.5 Mg ha^{-1} in the Kechemo and 61 Mg ha^{-1} in the Erene.

Table 4. Total length of rills, eroded soil volume and damaged areas in 30 fields at two sites in Chemoga watershed, Ethiopia

Parameter	Erene		Kechemo	
	Year 2000	Year 2001	Year 2000	Year 2001
Length (m)	1628.0	1520.2	1575.8	2404.4
Volume (m^3)	271.9	239.5	56.2	69.5
Damaged area (m^2)	1036.3	953.5	533.2	658.2
Damaged area out of total area (%)	2.2	2.0	1.9	2.4

Because of exclusion of interrill erosion, the measured rill erosion rates would be an underestimate of the actual rate of soil loss. According to Govers (1991), the contribution of interrill erosion can be more than 30% of the total soil loss in fields where rills are present. Assuming that the measured rill erosion rates underestimated soil loss by 30%, the actual soil loss rates were around 18 Mg ha^{-1} in the Kechemo and 79 Mg ha^{-1} in the Erene. These estimates are in agreement with the range of soil erosion rates measured in a nearby experimental micro-watershed, the Anjeni, located ~40 km northwest of the Erene. In five years of monitoring, soil erosion from cultivated fields, under the traditional land use practices, in the Anjeni ranged from 17 Mg ha^{-1} to 176 Mg ha^{-1} per annum (Herweg and Ludi, 1999).

Compared to the average soil loss rates estimated to occur from cultivated fields in the country (42 Mg ha^{-1} yr^{-1}) (Hurni, 1993), the estimated soil loss rates in the Kechemo were much lower. This is probably because of the nature of the rainfall, specifically its intensity, and characteristics of the soils such as texture, bulk density and infiltration capacity. In the Erene, the estimated soil loss rates were higher than the estimated national average value. But, the values are in agreement with the measured values in the experimental Anjeni catchment, where erosion rates as high as 130 to 170 Mg ha^{-1} yr^{-1} are not uncommon in cultivated fields (Herweg and Stillhardt, 1999), which has similar physical environmental and land use conditions. The difference between the two sites in the number of rills and eroded soil volumes are related to differences in the biophysical factors such as rainfall characteristics, slopes of the surveyed fields and soil properties. There was no difference in land use and management practices between the two sites to provide any explanations, except for the presence of fields cultivated with *tef* in the Erene.

However, the number of rills was not exceptionally higher in the *tef* fields, though rills tended to be larger in their dimensions. The inter-annual variations were largely attributable to the variations in the amount and temporal pattern of the rainfall between the years.

The area of actual damage, the surface area covered by the rills themselves, was more or less equal at the two sites (~ 2.1% of the total areas surveyed) (Table 4). These areas showed the direct impact of rill erosion on productivity of the cultivated fields via reduction of the total areas. However, the impact of rill erosion is much more than just a reduction in the area of productive land. Rill erosion is a result of surface runoff and associated sheet wash, which is a process that selectively removes fine material and organic matter, which are very important determinants of land productivity.

Rill classification

Classifying of the rills by taking into account both depth and width dimensions simultaneously, as suggested by Herweg (1996), was not possible because widths varied widely. Hence, only depth was used to classify the rills into size categories. Accordingly, four classes of rills were identified: small (or shallow) (≤ 15 cm), medium (16-30 cm), large (31-45 cm) and very large (≥ 46 cm).

Following this classification, all of the rills in the Kechemo fall within the small and medium size categories, the first accounting for the lion's share (Table 5). Many of these small rills ended within the same field as where they started, and showed sedimentation features. Sedimentation within the same field indicated redistribution of material. Though the sediments were left within field boundaries, fine materials and organic matter, which play vital roles in soil productivity, could have been transported outside the fields suspended in surface runoff. The fact that the majority of the rills were small and ended within the same fields, despite the steep slopes of the fields monitored in the Kechemo suggested that rainfall during the study period was not very erosive and/ or the soils are not very erodible types. That is, it somehow indicates a decrease in surface runoff, and consequently erosion, with distance downslope. On the other hand, the total number of rills in this site being much larger than the number of rills in the Erene agrees with results of experimental studies that erosion of soils with predominantly silty and sandy textural composition is mainly by rilling (Mosley, 1974).

Table 5. Soil erosion caused by four categories of rills in 30 fields at two sites in Chemoga watershed, Ethiopia

	Erene				Kechemo			
	Year 2000		Year 2001		Year 2000		Year 2001	
Size of Rill[a]	No. of rills	Total soil loss (m^3)	No. of rills	Total soil loss (m^3)	No. of rills	Total soil loss (m^3)	No. of rills	Total soil loss (m^3)
Small	4	8.3	5	9.4	98	51.8	151	60.5
Medium	38	164.1	33	158.0	3	4.3	3	9.0
Large	4	52.0	2	26.4	0	0	0	0
V. large	1	47.5	1	45.6	0	0	0	0
Total	47	271.9	41	239.5	101	56.2	154	69.5

[a]Small (≤ 15 cm), medium (16-30 cm), large (31-45 cm) and very large (≥ 46 cm).

In the Erene, about 90% of the total rills were in the small and medium size classes; and the very large rills were the least in number (~2%) in both of the years of monitoring (Table 5). The medium-sized rills contributed the largest share to the total soil loss, matching the number of the rills. However, the contribution of the small and medium rills to the total soil loss and total area of actual damage was less than their proportionate contribution to the total number of the rills. In contrast, the contribution of the large and very large rills to total soil loss and area of actual damage by far exceeded their proportionate contribution to the total number of the rills. This suggests that, in terms of total volumes, controlling fewer but larger-sized rills can retain more soil than controlling smaller but more numerous rills (e.g. for controlling a downstream sedimentation problem).

Temporal variations in rill erosion

The temporal variations in rill erosion were mainly reflections of the temporal distribution of the rainfall. Figure 2 shows cumulative eroded soil volumes and ten-daily cumulative rainfall amounts over the five months (May to September) in the Erene (measured at Debre-Markos) and Kechemo (measured at Rob-Gebeya). Rainfall showed both inter-seasonal and intra-seasonal variations. The five months total rainfall amount was 1177 mm in 2000 and 981 mm in 2001 in the Erene, and the corresponding values in the Kechemo were 1066 mm in 2000 and 1171 mm in 2001. That is, the five months rainfall amount in Erene in year 2001 was less than that of year 2000 by nearly 17%, whereas in Kechemo, the five months rainfall amount in year 2001 was more than that of year 2000 by nearly 10%. In both of the sites, the rainfall was heavily concentrated in the two months of July and August in both of the two years of monitoring.

The inter-seasonal distribution of rill erosion generally matched the inter-seasonal distribution of the rainfall amount (Fig. 2). It was higher in year 2000 in the Erene, but higher in year 2001 in the Kechemo (Table 5, Fig. 2). The total volume of eroded soil during year 2001 in the Erene was less than that of the year 2000 by about 12%. In the Kechemo, the volume of soil eroded during year 2001 was more than that of year 2000 by nearly 24%. The difference in soil loss between the two years of monitoring was very striking in the case of Kechemo. This is to be explained by the fact that the rainfall was not only higher in total amount during the second year, as compared to the first, but also much more concentrated in the three months of June, July and August. The total rainfall during these three months accounted for 81.7% of the seasonal total in the second year, as opposed to 67.1% during the first year. A similar explanation holds for the higher soil loss in the Erene in the first year than in the second. In addition to being higher in total amount, the rainfall was also more concentrated in the months of June, July and August in the first year. The three months total rainfall accounted for 71.5% of the seasonal total in the first year, as opposed to 68% in the second.

Soil erosion also showed intra-seasonal variability. In Erene, the period of peak erosion occurrence was the month of June, which accounted for approximately 67% of the total soil loss in 2000 and 68% of the total in 2001 (Fig. 2). This indicates that the period of peak erosion occurrence was before the time of highest rainfall occurrence. This was associated with the beginning of intensive rainstorms in June, after the long dry season, and a limited degree of soil cover. Only a few more rills were formed in the months of July and August. The difference in the rill erosion magnitudes between the months of July and August was rather small. In other words, much of the soil loss occurred in a limited period of time when erosive events coincided with conditions of high vulnerability of the soils to erosion. This finding is in agreement with a conclusion from measurements at two experimental stations (Anjeni and Andit Tid) in Ethiopia, which reported that, on average, rainstorms that account for only 20% of the annual rainfall amounts cause some 80% of the annual soil losses (Herweg et al., 2002).

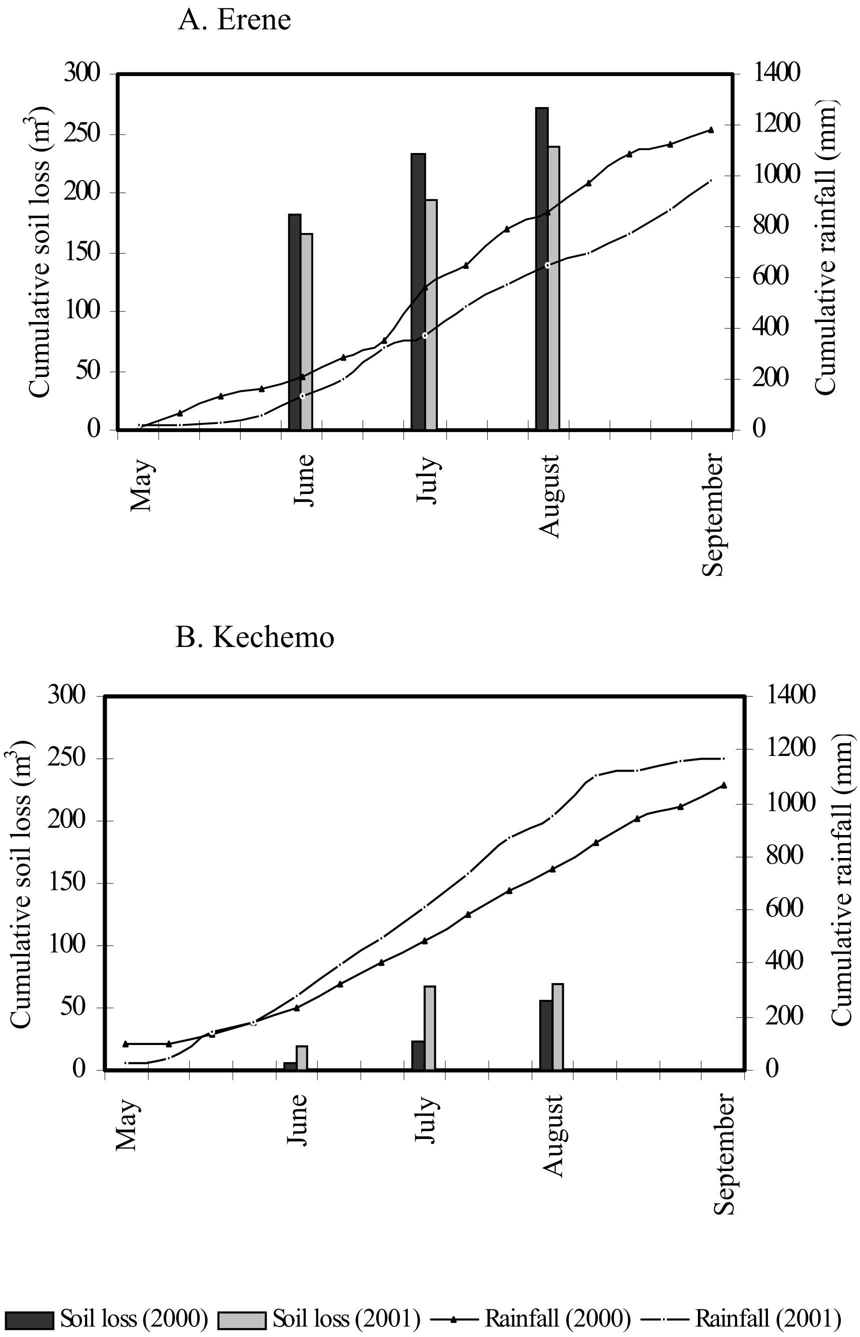

Figure 2. Temporal distribution of rainfall and rill erosion in two study sites in Chemoga watershed, Ethiopia

In the Kechemo, much of the soil loss occurred in July (~ 67% of the total eroded soil volume) in the year 2001, and predominantly in August (~ 59% of the total eroded soil volume) in the year 2000. The periods of peak rainfall and peak erosion occurrence were very close to each other at this site. The fact that rill erosion was less in June in both of the years of monitoring was attributable to the nature of the rainfall in the area (specifically its low intensity) and the infiltration capacity of the soils. As shown in Table 1, the soils in this site are characterised by favourable conditions for a high infiltration capacity (very low bulk density, high soil organic matter content and sandy texture). Because of the high infiltration capacity, coupled with the low intensity of the rainfall, surface runoff generation was not a widespread phenomenon until the month of July, when the soil profile became sufficiently saturated.

Also, because of the low rainfall intensity the surface roughness created by plowing remained an effective obstruction for surface runoff occurrence and consequent formation of rills during the early periods of the wet season. In the year 2000, much of the rill erosion occurred in the month of August. This was mainly because of the small rainfall amounts in the months of June and July in that particular year, much of which had to fill the soil moisture storage requirement before surface runoff was generated. The increased soil erosion while the ground cover was improving might appear surprising. However, it shows the importance of antecedent soil moisture conditions for runoff generation and rill formation at this particular site. Herweg et al. (2002) also reported that high soil losses were measured even when the soil cover exceeded 70%, depending on erosive circumstances, in the above-mentioned experimental stations in Ethiopia. Even though measured data are unavailable, it was observed during the fieldwork that surface runoff generation was largely infiltration-excess type (Hortonian overland flow) in the Erene, but saturation-excess type (saturation overland flow) in the Kechemo; both processes as described in Dingman (1994).

Topographic position of the fields and rill erosion

The volume of eroded soil and area damaged by the rills showed variations with the topographic position of the fields (Fig. 3). In both sites, the fields in midslope positions were more vulnerable to rilling. The explanations are to be found in the processes of surface runoff concentration and initiation of rills as channels for overland flow. In the upslope fields, surface runoff has to flow over a critical distance before concentration and rilling occurs; and in the downslope fields, the large amount of sediment carried by the surface runoff limits the scouring capacity of the flow and sedimentation becomes the important process. The critical distance over which surface runoff has to flow before concentration into rills starts varies with the slope angle of the fields. Generally, the critical distance and critical angle are inversely related (Govers, 1991). The critical distance is also affected by the infiltration characteristics of the soils (Morgan, 1995). The higher the infiltration capacity of the soils, the longer will be the critical distance. In the fields located upslope sheet wash and splash were the dominant form of soil erosion by water (field observation).

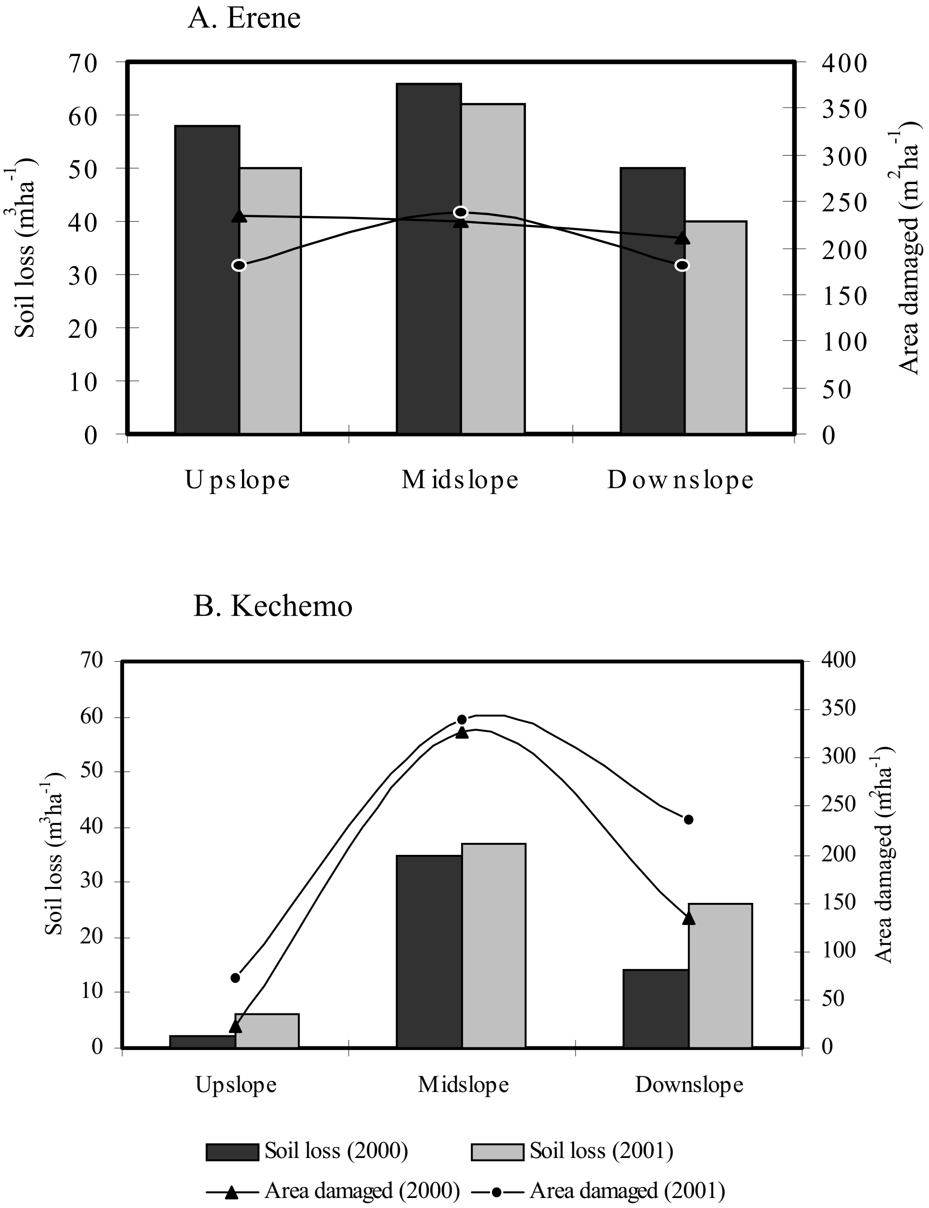

Figure 3. Spatial distribution of rill erosion and area damaged in two study sites in Chemoga watershed, Ethiopia

In the Erene, the eroded soil volume from the midslope fields was 1.2 times that from the upslope fields and 1.4 times that from the downslope fields. Similarly, the area of actual damage in the midslope fields was 1.1 times that from the upslope fields and 1.2 times that from the downslope fields. In the Kechemo, the eroded soil volume from the midslope fields was 9.5 times that from the upslope fields and 1.8 times that from the downslope fields. In addition, the area of actual damage in the midslope fields was 7.0 times the area of actual damage in the upslope fields and 1.8 times that from the downslope fields. As these comparisons indicate, the differences between the upslope, midslope and downslope fields in terms of both eroded soil volumes and areas of actual damage were more conspicuous in the Kechemo than in the Erene. This was because the upslope fields in the Kechemo received a lesser amount of surface runoff from areas in the upslope position, being more like slopes close to water divides; while in the Erene, the upslope fields themselves received large amounts of surface runoff from areas in the upslope position. The inflow of surface runoff from areas in the upslope position was not an unexpected occurrence given their position along the slope, which was not at water divides. Also, no attempt was made to divert the inflow of surface runoff into the selected fields because the objective was to assess the magnitude of soil erosion in most commonly cultivated types of slopes in the area under conditions of unmodified reality, as they are used and managed by the farmers.

Implications of the spatio-temporal variations of erosion on decisions for SWC measures

As described above, soil erosion showed significant spatio-temporal variations in the study sites. These variations have important implications on selection and design of SWC measures. Inter-seasonal and intra-seasonal variability in erosion means that much of erosion damage on agricultural lands occurs during a limited number of wet seasons of erosive conditions and periods of erosive rainstorms within the seasons. Hence, to be effective, SWC measures should be designed to tackle the worst scenarios, which cause the bulk of soil losses. For instance, the threat of soil loss was found to be most severe in June in the Erene and in July and/or August in the Kechemo. Accordingly, the rainfalls of the respective months may be used as ‘design storms’ to determine dimensions and spacing of structural SWC measures in the two study sites.

Similarly, the differences between and within the sites in the severity of the problem of soil erosion suggest that SWC measures should be site-specific. When SWC measures are selected and designed for site-specific situations, they are more likely to be accepted and adopted by the local farmers (Azene, 2001). Woldeamlak and Sterk (2002) reported that SWC works undertaken in the Chemoga watershed during 1999-2000 did not consider site-specific conditions. The result was that the conservation structures were poorly implemented and maintained, and then doing more harm than good (Woldeamlak and Sterk, 2002). For soil erosion is a site-specific problem, as clearly shown by this study, applying site-specific conservation measures must be realistic and acceptable to the farmers. Generally, farmers’ acceptance and adoption of SWC measures will be enhanced if the introduced technologies can also be extensions and outgrowths of indigenous practices (Critchley et al., 1994; DeWalt, 1994; Reij et al., 1996). In the study area, there are a range of land management practices meant for erosion control and enhancement of soil fertility (Lakew, 2000). These indigenous practices can be improved or used as points of entry for the invention and dissemination of new and more effective technologies.

Conclusions

In this study, a survey methodology that focused on rills was employed to assess the magnitude of soil erosion from cultivated fields in two micro-watersheds, namely Kechemo and Erene, situated in the Chemoga watershed. Assuming a 30% contribution from interrill erosion, soil loss was estimated at 18 Mg ha^{-1} in the Kechemo and 79 Mg ha^{-1} in the Erene. These estimates, which are well in agreement with results obtained by intensive measurements in a nearby experimental micro-watershed, revealed that soil erosion is a threat to agricultural production in the study area and conservation measures are needed. Soil erosion showed significant spatial (between and within the two sites) and temporal variations. This suggests that SWC technologies that fit well into local-scale circumstances must be realistic and acceptable to the farmers. The blanket approach, which is still underway in the Chemoga watershed and in many parts of the country at large, needs to be changed if SWC efforts are to bring about meaningful results. Planning and implementation of SWC measures ought to be undertaken through farmer-participatory processes to ensure its sustainable adoption on the farm. Moreover, the problem of soil erosion should be tackled in the watershed context because there is an obvious physical interdependence between upstream and downstream areas, indicating that conservation in one farm will do little if the other farms in a higher position are not conserved. Thus, the watershed framework is apparently the logical unit for SWC and natural resources management, in broad terms (Hurni, 1985b; Sivamohan et al., 1993).

This study also confirms that the survey approach gives good semi-quantitative information on soil erosion in real life situations of diverse farming and land use practices in a quick and inexpensive way, as opposed to monitoring experimental plots and watersheds. Thus, it is commendable for practical conservation-oriented soil erosion assessment purposes. Furthermore, rills being visible features, measurement of rill erosion can be conducted with local farmers. The farmers will then appreciate the quantity of soil lost to erosion every wet season and how much fertile soil applying conservation measures can retain. In other words, rill erosion survey can facilitate a farmer-participatory erosion research and conservation planning and implementation, aiding to replace top-down and technocratic approaches by bottom-up and participatory processes.

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Chapter 6

Socioeconomic circumstances of farm households in the northwestern highland Ethiopia: a case study in the Chemoga watershed

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Socioeconomic circumstances of farm households in the northwestern highland Ethiopia: a case study in the Chemoga watershed

Abstract

This study reports results of a survey of smallholder farmers' circumstances in the Chemoga watershed, northwestern highlands of Ethiopia. It is revealed that the people are poor, living on an average annual income ranging from Birr 779 to Birr 1692 (1.00 Birr ~ 0.125 $US) per household, which has 6.3 members on average. Crop production and livestock rearing contributed to more than 93% of their total incomes and sale of trees and wood provided for around 3%. Only very few households were found to be engaged in off-farm activities as additional sources of income. Land and livestock are therefore the bases of livelihood for the people. On the other hand, land has become scarce because of the increasing population. As witnessed by the surveyed households, landholdings per household have been declining, and productivity of croplands has declined over time. Likewise, there has been a decreasing trend in the number of livestock owned per household, while the total livestock population of the communities has increased and caused overgrazing and feed shortages, and necessitated the use of crop residues as livestock feed rather than soil conditioner. These negative trends in resource availability, while the population is increasing, suggest that the future is bleak. Hence, interventions that integrate development and conservation measures are urgently needed. Generally, solutions should include improving productivity of the farming system through technical interventions, creating off-farm employment opportunities to the population and easing human and livestock population pressures on the land.

Key words: farm households, poverty, population pressure, resource degradation, Ethiopia

Introduction

Ethiopia, the second most populous country (64 million) in Africa (Sonneveld, 2002) is one of the least developed countries in the world with a per capita GNP of US$110 (Berhanu and Seid, 1999). Agriculture is the mainstay of the national economy. Over the past three decades, growth in the agricultural sector has been unable to keep pace with the population growth. Food production lingered behind the growth of population. Between 1980 and 1997, for instance, the population of the country grew at a rate of about 3% per annum while cereal crops production grew only by a rate of 0.9% per annum (Mulat, 1999). This means that per capita food availability has been falling, food insecurity growing and poverty worsening. The country is presently one of the major food aid recipients in Africa. As Clay et al. (1999) reported, over the 1985-1996 decade, annual cereal food aid ranged from 200,000 to 1.2 million tons, which was equivalent to 3.5% and 26% of the total national production, respectively. Resource degradation is identified to be one of the reasons for this distressing trend in the food production and economic growth (TGE, 1992; Hurni, 1993; Sutcliffe, 1993; Shiferaw and Holden, 1999).

Of the forms of resource degradation, soil erosion by water is the most pressing. According to Hurni (1993), average soil loss rates on arable lands is 42 $tha^{-1}yr^{-1}$, which by all measures exceeds the rate of soil formation. By the mid 1980s, FAO (1986) estimated that soil erosion reduces national food production levels by around 2% per annum. The traditional practice of fallowing for soil improvement is largely abandoned because of high man-land ratios. The shortage of fuelwood has necessitated the use of manure as source of energy rather than soil fertilizer (Woldeamlak, In press). Similarly, crop residues are needed as feed for livestock, sources of domestic energy and some as covers for roof making them too scarce to be used for soil fertility replenishment (Woldeamlak, 2001). On the other hand, use of artificial fertilisers and other factor inputs that will improve productivity such as improved seeds, herbicides and pesticides is very low and, indeed, are beyond the reach of the majority of the farmers. The outcome has thus been inexorable loss of land productivity and growth of food insecurity, and emanation of conditions for more household as well as national level food insufficiency and insecurity.

Therefore, interventions to reverse the trend of resource degradation and alleviate the heightening rural poverty are urgently needed in Ethiopia. Planning for effective and sustainable resource conservation requires a detailed understanding of the physical environmental settings that shape socioeconomic systems, and the socioeconomic circumstances of the smallholder farmers, the sector contributing the bulk of the national crop and livestock outputs. The aim of this study is to describe socioeconomic circumstances of the smallholder farmers in relation to the status and dynamics of natural resources in a typical watershed (the Chemoga watershed) in the northwestern highlands of Ethiopia.

The Chemoga watershed- the environmental setting

The Chemoga watershed lies within $10^0$18'N to $10^0$39'N and $37^0$44'E to $37^0$53'E. In administrative terms, it is located in Gozamen woreda (district), East Gojjam Zone, Amhara Regional State. Situated at some 300km distance northwest of Addis Ababa, the watershed forms part of the northwestern highlands of Ethiopia. With a total area of 364 km^2, it is inhabited by a total population of about 40,768, as estimated from the rural population density (112 persons/ km^2) of the Gozamen woreda (Gozamen Woreda Office of Agriculture, 2001). The Chemoga watershed is characterised by diverse topographic conditions. The elevation ranges from 2420m to nearly 4000m. A mountainous and highly dissected terrain with steep slopes characterises the upstream part of the watershed; and an undulating topography and gentle slopes characterise the downstream part.

According to the traditional agroclimatic classification system, which considers only temperature and altitude, the Chemoga watershed lies within *dega* (temperate) and *wurch* (alpine) zones. The climatic condition is generally humid. As measured at Debre-Markos ($10^0$20'N, $37^0$40'E and elevation 2411m), the mean annual temperature is 14.5^0C with a range from 13.2^0C in July and August to 17.3^0c in March. Average annual total rainfall is 1300 mm. The rainfall pattern is unimodal with a peak between July and August. More than 75% of the total rain falls in the four months of June to September (*kiremt* season). The dry months are from November to February (*bega* season), when less than 5% of the annual total rainfall occurs. Since the watershed lies at a higher elevation than Debre-Markos, temperatures are lower and rainfall probably higher than these values. Average annual total potential evapotranspiration (PET), as estimated with the Thornthwaite's method (Thornthwaite, 1948), is 855.7 mm. The monthly rainfall exceeds the calculated PET only during the *kiremt* season. The uneven distribution of the rainfall gives rise to a serious shortage of water during the dry season in some parts of the watershed.

Farm household survey

The data for this study came from a structured household survey conducted between March and May 2000. The procedure of the survey was as follows. First, four sample villages, the lowest tiers in the administrative structuring of Ethiopia, were selected on purpose to cover the upstream, midstream and downstream reaches of the study watershed (Table 1). Then, lists of households in each of the villages were obtained from the respective village administrations. With the lists, a systematic random sampling procedure was used to select a total of 133 sample households. In cases where a selected household head happened to be away from home for a long time or was unwilling to be interviewed, a randomly selected substitute was included. Given the relative homogeneity of the subsistence farmers in the four villages in terms of physical environmental factors and resource endowments, the sample size of each village would be reasonably representative of the population it stood for.

The survey questionnaires were comprised of both closed- and open-ended types of questions and covered various issues: household demographic composition, landholding, crop production and livestock tending, off-farm employment, income from sale of wood and trees and household expenditures. The researcher and four enumerators, all of whom speak the local language, conducted the interview. The enumerators were first trained by the researcher about how to present and explain the questions to the respondents. They were also advised to inform each respondent of the purpose of the survey before starting the interview. The interviews were conducted by going to each interviewee's homestead. The time taken by an interview ranged between 60 and 90 minutes. Early mornings and late afternoons were convenient times for the interviewees. Attempt was also made to crosscheck responses of the farmers on such questions as landholding sizes and number of livestock owned from records of the village administration, as farmers sometimes understate these fearing that land use fees and other government obligations might be increased. In addition to the formal questionnaire survey, informal discussions were also held with some farmers to generate additional information on the issues covered by the structured questionnaire.

The data generated by the structured questionnaires were analysed using the frequencies and descriptive procedures of the SPSS release 10 (Bryman and Cramer, 2001). The qualitative data generated by informal discussions with the local people were used to substantiate the quantitative results from the structured questionnaires.

Table 1. The study villages in the Chemoga watershed

Village	Position in the watershed	General elevation (m)	Climatic zone	Total N^{o}. of households	Sample size
Dangule	Upstream	3200-3800	Alpine	1121	38
Sinan	Upstream	2800-3200	Temperate	868	31
Keny	Midstream	2600-3000	Temperate	909	32
Yegagna	Downstream	2450-2600	Temperate	772	32

Socioeconomic circumstances of the farm households

Demographic profile

Table 2 shows the demographic composition of the sample households. The total population of the 133 households was 834, of which 437 were males and 397 were females. The male population outnumbered the female population giving a sex ratio of 110%. The average household size for the overall households was 6.3, with a slight variation between the four villages. It was 6.0 in Dangule, 6.2 in Keny, 6.6 in Sinan and 6.3 in Yegagna. But these averages cannot be indicators of the gross fertility levels of the population. By the average household size it was to refer to the number of individuals living under one roof; thus excluding children of some households who may have established their own households. Nearly all the households were found to be nucleated families.

The overwhelming majority of the population was young. The population segment under the age of 15 years accounted for 53% of the total. The number of individuals whose age was above 64 was only two. The working age population, following the conventional categorization, was 389. The age-dependency ratio was therefore 114.4%; which was composed of 113.9% young-age dependency and 0.5% old age ratio. The fact that the majority of the population is young implies the pressure on the land resource is on the increase.

Table 2. Demographic composition of the sample households- N^{o}. of individuals by age and sex

Age groups	Dangule		Keny		Sinan		Yegagna	
	Male	Female	Male	Female	Male	Female	Male	Female
0-14	66	43	52	55	51	60	62	54
15-64	66	53	48	44	44	48	47	39
≥ 65	1	0	0	0	0	0	0	1

Land holdings

Land is the basic source of livelihood in rural Ethiopia. Land has been under state ownership since the 1975 national land reform, and there have been many redistributions and readjustments since then, in an attempt to accommodate newly forming households. In the study region (Amhara Regional State), the last readjustment was conducted in 1997. The frequent redistribution has led to the subdivision of farmlands into ever-smaller parcels. In the sample villages, the average holdings were less than a hectare in Dangule (0.97 ha) and Sinan (0.89 ha) villages, just over a hectare in Keny (1.2 ha) and about 1.8 ha in Yegagna (Table 3). Taking the average household sizes of the respective villages, per capita holdings were 0.16 ha in Dangule, 0.19 ha in Keny, 0.13 ha in Sinan and 0.29 ha in Yegagna. The inter-village difference in sizes of farmland per household is a result of several factors: total area and nature of terrain of the villages, population sizes and extent of non-utilizable degraded lands in the villages. Also, there was a significant variation in the size of holdings among households. Of the surveyed households, two had more than 2 ha and three had no land at all. In fact, it was learned from informal discussion with farmers that there were a considerable number of households in all the four villages who possessed no piece of land. The pattern was similar to the national level reality.

According to CSA (1995), some 80% of the Ethiopian farmers in the highlands (>1500m) cultivate less than 1 ha of farmland.

Sharecropping was the main mechanism of gaining access to cropland by the landless. The sharecropping arrangements were between the landless households and those households that lacked the means of cultivation such as oxen, labour or seed, which were often women-headed households or elderly people. According to the commonly accepted sharecropping arrangement, the two parties each took half of the produce from the rented plot. The other means of gaining access to cropland, mainly for newly formed households, was inheritance from parents, which has contributed significantly to land fragmentation. It is however, becoming less important as the size of land available to parents has become very small. Given the increasing rural population, while land is fixed, increasing landlessness will be a critical problem. Resettlement of people from the densely populated highlands to the relatively sparsely populated lowlands could be a short-term alternative. Nonetheless, the current administrative regionalization, which is based on ethnic-linguistic grouping, will pose a serious constraint for such a purpose.

Table 3. Household size and land holdings of households- % of respondents

	Dangule	Keny	Sinan	Yegagna
Household size (numb.)				
≤ 3	5.3	6.3	-	-
4-6	57.9	50.0	45.2	59.4
7-9	34.2	40.6	51.6	40.6
≥ 10	2.6	3.1	3.2	-
Total land held (ha)				
≤ 0.5	15.8	6.3	16.1	15.6
0.6-1.0	55.3	50.0	74.2	43.8
1.1-1.5	13.2	25.0	6.5	25.0
1.6-2.0	10.5	12.5	3.2	9.4
> 2.0	-	6.3	-	3.1

Nearly all of the interviewed farmers stated that croplands are becoming scarcer in their communities (95% of respondents). Some 10% of the respondents stated that their own holdings decreased by 50% over the past 10 years, while 6.5% and 9.7% indicated that their holdings decreased by 25 and 75%, respectively, over the same period. The decrease in land holdings was attributed to the increased population in the area (73% of respondents). Only few gave out land degradation and consequent abandonment as a reason, and still fewer reported that land was not scarce. The farmers were also asked whether their holdings were adequate to support their families and if not, to estimate size of farm that would be sufficient. 85.8% responded that their holdings were insufficient. Mean desired holdings expressed by the farmers themselves were 1.9 ha in Dangule, 2.0 ha in Keny, 1.7 ha in Sinan and 1.9 ha in Yegagna. Though their holdings were insufficient and many felt that cropland was getting scarcer, the majority stated that they would not like to resettle (78.4% respondents) even if they were to be taken to new areas where land might be abundant, because of the bad history of resettlement in the country.

The quality of farmlands varies considerably within villages, and in fact, within farms as well. This is taken into consideration during land redistribution and readjustment activities. The result is that farmers operate more than one parcels of land, which can be located long distances apart. The farmers included in the survey operated, on average, 3.3 plots in Dangule, 3.1 plots in Keny, 2.7 plots in Sinan and 3.5 plots in Yegagna. As it is often argued, fragmentation has negative effects on the intensity with which land can be utilized and crops managed. For instance, fragmentation causes croplands to be reduced to narrow corridors running downslope. Such land strips will be inconvenient to apply structural soil and water conservation measures. Moreover, the linear shapes will dictate plowing to be carried out along the slope rather than across, which will significantly increase the magnitude of tillage erosion. Thus, these very small and fragmented holdings are, generally, conducive neither to optimisation of agricultural practices nor the application of land management measures. However, in view of the majority of the surveyed farmers the advantages of fragmentation, such as risk distribution and enabling fair access to good quality soils, outweigh the disadvantages (86.3% of respondents).

Household members provided the labour that is needed for the farming operation. The majority of the surveyed households had adequate supply of labour. As it can be seen in Table 3, some 53% of the households had 4 to 6 members; and some 41% had 7 to 9 members. On the other side, 56% of the households possessed only 0.6 to 1.0 ha of farmland. Only 2.3% of them owned more than 2 ha. More explicitly, the farmers were asked whether labour shortage was a problem in their farming activities. More than 72% of the respondents asserted that labour supply was not a constraint in their farming operation. According to these farmers, there was, indeed, disguised unemployment of the labour force due to the land shortage.

Crop production

Crop production is the major source of income to the farmers in the study area. The main crops cultivated are barley (*Hordeum vulgare*), oats (*Avena sativa*), horse beans (*Vicia faba*) and potatoes (*Solanum tuberosum*) in the Dangule village; and in the Sinan village wheat (*Triticum vulgare*) and onion (*Allium cepa*) are cultivated in addition to those crops cultivated in Dangule. Being at a lower elevation than these two, *tef* (*Eragrostis tef*) is the other crop to the farmers in Keny and Yegagna additionally cultivated to those cultivated in the Sinan village. In Dangule and Sinan, potato is grown twice a year but depending on whether sufficient rain falls in a particular year. All other crops are cultivated once in a year.

Table 4 shows estimated incomes of the sample households from crop production at averages of *bega* and *kiremt* prices for the year 1998/99 (1991 E.C.). The produces are expressed in terms of monetary equivalents to enable comparisons and better understanding. The average prices for the different crops vary between the seasons. Generally, it is low in the *bega* season and high in the *kiremt* season. Barley and oats account for the largest share of the total annual income of households in Dangule (75% of total) and Sinan (50% of total), while wheat is the most important crop in Keny (42% of total incomes), and in Yegagna tef is the most important (46% of total incomes). Farmers grow the different crops as a strategy to averse any risk, to spread out food availability and to adjust for local agroecological conditions.

Table 4. Estimated average incomes of the sample households from crop production (Eth. Birr) in 1998/99 (1991 E.C.) (Eth. Birr 1.00 = US$ 0.125)

Dangule		Keny		Sinan		Yegagna	
Crop	Birr	Crop	Birr	Crop	Birr	Crop	Birr
Barley/oats*	467	Barley/oats	428	Barley/oats	379	Barley/oats	188
Beans	52	Beans	92	Beans	219	Beans	22
Potatoes	107	Wheat	521	Wheat	65	Wheat	336
-	-	Potatoes	41	Potatoes	40	Potatoes	49
-	-	Tef	69	Onions	51	Tef	571
-	-	Onions	98	-	-	Onions	73
Total	626	Total	1249	Total	754	Total	1239

*When reporting to the survey team, some of the farmers did not distinguish between barley and oats because they considered oats as a type of barley.

The productivity of the different crops varies among the villages, as was learned during the survey. It was generally highest in Yegagna and lowest in Dangule. The farmers in all of the villages also witnessed that productivity of their plots had declined (93% of respondents) over the years. As reasons for the decline in productivity, 'ageing of the land' was repeatedly mentioned (48% of respondents). Other reasons given by the farmers include drought (26% of respondents), soil erosion (12% of respondents) and their inability to use chemical fertilizers because of the high cost (24% of respondents); and some gave other more household-specific reasons. The high cost of fertilizers as a problem was mentioned by the households in Keny and Yegagna, where nearly all of them used the input although at a very low rate of application. In Danglue and Sinan, none of the sample households used chemical fertilizers believing that the crops' response to fertilizers was zero due to the cold climates.

Livestock tending

As in all other parts of the Ethiopian highlands, livestock are an integral part of the sedentary life of people in the study area. Table 5 shows the number and types of farm animals kept by the surveyed households. The total number of farm animals of the surveyed households was 873, including cattle, sheep, horses and donkeys. This represents 6.6 farm animals per household. There were also 121 chickens, which is 0.9 per household. The composition of the farm animals was such that cattle accounted for 48%, sheep for 38% and horses and donkeys for the balance (14%). In terms of TLU, the total farm animals of the surveyed households were about 416. The average holdings of households were 3.1 TLU in Dangule, 2.8 TLU in Keny, 2.9 TLU in Sinan and 3.7 TLU in Yegagna. Sheep and horses dominate in Dangule and Sinan. In Keny and Yegagna, cattle are as important. Horses and oxen provide the draught power needed for the farming, and sheep and chickens are very important sources of cash and food for the rural households in Ethiopia.

The contribution of livestock as cash sources of the farmers is significant. For instance, in the year 1998/1999, sales of livestock, livestock products, chickens and eggs contributed to 14% of the total income of the surveyed households in Dangule and Keny and 20% in Sinan and Yegagna. Farmers usually sell farm animals to cover bigger expenses like land taxes and other government obligations. The horses and the few donkeys available give the service of locomotives to transport people and goods. They are a very essential means of transportation. Given the country's large physical expanse, physiographic irregularity and the indolent economic growth, the significance of equines as a mode of transport appears to remain indispensable for a long time to come.

Livestock are the source of manure that is used as organic fertilizer or for domestic fuel. As estimates indicate, 1 TLU produces 3.2 tons of manure per year (ILCA, 1981 quoted by Amare, 1981). As per this estimate, livestock of the surveyed households can produce a total of more than 1330 tons of manure per annum. This is equivalent to a considerable quantity of chemical fertilizers if used for soil improvement.

As elsewhere in the country, livestock ownership is used as a measure of wealth status of households in the communities studied. That is, livestock ownership is the main differentiating factor between the wealthier and poorer households. Thus, there is a social standing attached to the number of livestock owned regardless of the feed shortage. There is a serious shortage of animal feed. During *kiremt* season, livestock are dependent on heavily degraded (overgrazed) communal lands and on some crop residues collected during *bega* season. During *bega* season, crop residues are the main feed. Residues of wheat and barley are, however, also used as roof covers, specially in Dangule and Sinan villages, thus sometimes an absolute choice to be made is whether to use the residues as animal feed or as part of own shelter.

According to the farmers, the causes to the shortage of livestock feed are drought (18% of respondents), human population pressure and expansion of cultivation (49% of respondents) and livestock population pressure and overgrazing (3% of respondents); and the rest gave various reasons. Also, 34% of the respondents believed that common property nature of the grazing lands contributed to its degradation and shrinkage in area. On the other hand, 16% of the respondents firmly expressed that they would not suggest redistribution of the grazing lands amongst community members for privatized use. As a lasting solution to the problem of feed shortage, the farmers suggested increasing of grazing land areas (25% of respondents), introduction of controlled grazing systems (16% of respondents) and reduction of livestock numbers (10% of respondents). The rest suggested various and different solutions to the problem.

Regarding the trend in livestock numbers, the farmers indicated that there had been an overall increase at the village levels, while per capita holdings had been decreasing. Some 88% of the respondents stated that their own holdings had decreased, while 8% indicated that their holdings remained constant and 3% indicated that it increased. Reasons for the decrease in the number of livestock per household, mentioned by the farmers, include drought (28% of respondents), feed shortage (48% of respondents) and others (the balance). 48% of the respondents further added inadequacy of veterinary services as a problem in their livestock production enterprise. The increase in the overall livestock numbers shows a growing pressure on the land.

Table 5. Total number of livestock owned by the sample households

	Dangule	Keny	Sinan	Yegagna
Calves	13	8	11	30
Cows	23	20	20	42
Heifers	11	4	11	30
Horses	41	14	29	14
Oxen	31	42	23	55
Sheep	116	44	66	109
Donkeys	-	10	-	14
Young bulls	7	5	7	23
Chickens	30	25	34	32

Oxen are the engines of the subsistence crop production activities the households are engaged in. Lack of this main resource determines the vulnerability status of a household to food insecurity and seasonal food shortages. Oxen determine the efficiency of cropping. Hence, oxen ownership among the surveyed households is shown separately in Table 6. Nearly 22% of the households did not possess any ox; some 44% owned only a single ox; 33% had a pair of oxen and only two households were found to possess 3 oxen. At the national level, as well, some 30% of highland farmers were found to be without an ox in 1994/95 (CSA, 1995). To have no ox or even only one is a serious constraint on farming. The oxless farmers try to overcome this problem and get their plots of land plowed through several arrangements. These include leasing out of their lands for crop sharing, using ox pairing with others, exchanging human labour for oxen, pairing an ox with a horse and using a pair of horses. In Dangule and Sinan, in particular, horses are the most important means of plowing, either a pair of horses or an ox and a horse paired together.

Table 6. Number of oxen owned per household in the sample villages- % of respondents

No. of oxen	Dangule	Keny	Sinan	Yegagna
0	31.6	9.4	38.7	6.3
1	55.3	50.0	48.4	21.9
2	13.1	40.6	12.9	65.6
3	-	-	-	6.3

Expenditures

Table 7 shows items of expenditure and amounts of expenses which were incurred by the sample households in the four villages in the year 1998/99. The largest item of expenditure was for purchase of clothing. Purchase of food items such as salt, edible oil, coffee, sugar and spices, which are not produced by households themselves constituted the second largest item of expenditure in Dangule and Sinan, but the third largest in Keny and Yegagna preceded by that for purchase of chemical fertilizers. Then, religious festivities, such as for the commemoration of days of the Saints and for *mahber*, a social/mutual aid association which involves festivities, constituted the third major item of expenditure in Dangule and Sinan, but the fourth in Keny and

Yegagna. The other important items of expenditure were for purchase of kerosene for lighting purposes, land use fees, purchase of seeds and death-related expenses. There are also wedding-related expenses, depending on whether a household had any member who got married that specific year or not. These were found to be very low during the mentioned year because it was a year hit by drought; hence not included in the list of items of expenditure. The differences between the villages in amounts of total expenditure follow the same pattern as the total incomes.

Table 7. Items of expenditure and amount of expenses (Eth Birr) of the sample households in 1998/99 (1991 E.C)

Items of expenditure	Dangule	Keny	Sinan	Yegagna
Clothing	167	204	186	191
Community contribution	15	9	5	7
Death-related	41	17	35	23
Fertilizers	-	153	-	178
Food items	166	121	153	129
Kerosene	40	28	28	25
Land use fee	26	27	25	30
Religious festivities	84	112	147	88
Schooling children	11	12	22	13
Seeds	19	16	33	18
Total	569	699	634	702

Income-expenditure balances

Annual income-expenditure balances of the sample households are given in Table 8. Both the income and expenditure figures are as estimated by the households themselves. For the calculation of the annual incomes of the households, five activity categories were identified: crop production, livestock rearing, off-farm works, sales of wood and trees and remittances. From all of these activities, annual incomes of the households in all the four villages were generally low. Annual incomes from crop production ranged from Birr 1249 in Keny to 626 in Dangule at average (of *bega* and *kiremt*) prices. Incomes from sales of livestock and livestock products including chickens ranged from Birr 112 in Dangule to Birr 351 in Yegagna.

Because of the relative agro-ecological positions, the households in Dangule and Sinan are much poorer than those in Keny and Yegagna. Total annual incomes followed the elevation gradient, decreasing rapidly as elevation increases. This shows the magnitude of influence of the physical environmental factors on the wellbeing of these subsistence farmers. There will be a difference of about Birr 300, on average, in annual incomes from crop production comparing the *bega* and *kiremt* prices, the higher being at *kiremt* prices. Farmers will thus get better cash if they could sell their produce in the *kiremt* season. However, they are required to pay land tax and other governmental and social obligations (e.g. religious festivities) in the *bega* season, hence they are deprived of the chance to use raised market prices of the *kiremt* season.

Table 8. Income-expenditure balances of the sample households (Eth Birr) in 1998/99 (1991 E.C.)

Sources of income	Dangule	Keny	Sinan	Yegagna
Crop production*	626	1249	754	1239
Livestock products	112	224	216	351
Off-farm activities	0	62	86	64
Remittance	0.4	1.9	3.2	9.4
Sale of trees and wood	41	29	30	29
Total income	779	1566	1089	1692
Total expenditure	569	699	634	702
Income-expenditure balance	210	867	455	990

*Computed at average prices (of *bega* and *kiremt*) for each crop.

Incomes from off-farm activities and remittances were scanty. For instance, only 13% of the surveyed households were engaged in additional off-farm activities, where the definition of off-farm activities included all activities outside of one's own farm: working on another farmer's farm, petty trading, weaving, carpentry, smithing and pottery. Hence, in spite of the fact that land has become scarce and degraded and productivity declined over time, as expressed by the farmers themselves, it seems that the farmers lack flexibility or the opportunity to move away from their age-old practices and engage in other income generating activities. This indicates the need for an effective external intervention along this direction so that part of the population will be taken off the land. The other important (third largest) source of income was from sale of wood and trees. This contributed to 5.3% of the total income of households in Dangule, 1.8% in Keny, 2.7% in Sinan and 1.7% in Yegagna. Some 18% of all the households responded that they generated some income by selling trees and fuelwood. Some of them sold trees planted by themselves, but others sold wood from natural woodlands and forests. The latter is rather a threat to the remaining meagre natural vegetation resource in the watershed. The last raw in the table (Table 8) shows the net balance between total annual incomes and expenditures. These income-expenditure balances show the proportion of households' produces that are used for domestic consumption purposes. Indeed, not all reflected by the balance is available for domestic consumption as allotments of crop produces should be set aside for seeds for the next cropping season.

Conclusions

In the study watershed, as is the case in much of rural Ethiopia, the people are poor, living on average annual incomes ranging from Birr 779 in Dangule to Birr 1692 in Yegagna per household, which has 6.3 members on average. Crop production and livestock rearing contributed to more than 93% of the total annual income of the households, and nearly 3% was secured from sale of trees and wood. Only very few households were found to be engaged in off-farm activities as additional sources of income, indicating the heavy dependence on the land. Land and livestock are the bases of livelihood for the people. On the other hand, land has become scarce and landholdings per household have been declining because of the increasing population. Moreover, productivity of croplands has declined over time due to, as described by the surveyed households, 'ageing of the land', drought, soil erosion and their inability to use chemical fertilizers because of its high cost. The scarcity and decrease in productivity of croplands has thus contributed to lower production of crops.

There has also been a decreasing trend in the number of livestock owned by households, contributing towards poverty of the people. On the other hand, increase in the human population has caused an overall increase in the total livestock population in the communities, creating pressure on grazing lands and shortages of feed. The shortage of feed was identified to be one of the main reasons, the other being drought, for the decrease in the number of livestock owned by the households. Heavy grazing removes protective vegetation cover, and leads to soil compaction, surface sealing, increased runoff, and consequently soil loss in grazing lands. Not only does it effect clearing of vegetation and the subsequent effects on the grazing lands, but also affects cultivated lands, in much the same way, because free roaming feeding on crop residues takes place after harvesting.

The people in the study area are therefore facing problems of poverty and resource degradation, which require prudently composed solutions that integrate development and conservation measures. In general terms, solutions to the problem should include improving productivity of the farming system through technical interventions, creating off-farm employment opportunities to the population and easing human and livestock population pressures on the land. The local people must be genuinely involved in all initiatives of development and resource conservation, to ensure its sustainability. Involvement of the local people can be enhanced where development and conservation interventions are addressing priorities and needs of the people.

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Chapter 7

Household level tree planting and its implications for environmental management in the northwestern highlands of Ethiopia: a case study in the Chemoga watershed, Blue Nile basin

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Household level tree planting and its implications for environmental management in the northwestern highlands of Ethiopia: a case study in the Chemoga watershed, Blue Nile basin

Abstract

The unsustainable exploitation and destruction of forests is a serious environmental concern in the developing countries of Africa. One of its main deriving forces is the growing population causing a growing demand for fuelwood. In Ethiopia, like in any developing country, there is a heavy dependence on and a growing demand for fuelwood. This dependence has been contributing to a widescale deforestation, as stated in various reports. Contrary to these reports, a study in the Chemoga watershed found a slightly increased forest cover during the past four decades, which was ascribed partly to households' tree planting practices. The objective of this study was to examine household level tree planting activities in reference to biofuel consumption patterns in four sample villages in the watershed. The results indicate that fuelwood and cattle dung accounted for nearly 100% of the domestic energy consumption, with cattle dung contributing 34% of the total. Fuelwood and dung combined, per capita biofuel consumption was estimated at 511 kg yr^{-1}, but with variations between the villages and socio-economic groups. Supply appears to have influenced the quantity of biofuels used. The scarcity of wood for fuel and other uses has forced households to plant trees. This has contributed to the slightly increased forest cover of the watershed at the present as compared to that four decades ago. Number of trees planted showed variation between the villages and socio-economic groups, which is attributable to physical and human factors. In promoting tree planting, (agro)foresters and environmental management planners should therefore take into account local level biophysical and socioeconomic realities. This (agro)forestry practice is a good short-term solution to the problem of fuelwood shortage, and also has many positive implications for environmental management and agricultural production. Thus, it has to be encouraged. Spatially aggregated, local level agro(forestry) practices contribute positively towards global ecosystem health.

Key words: cattle dung, deforestation, environmental management, fuelwood, household, agroforestry

Introduction

The unsustainable exploitation and destruction of forests is a serious environmental concern in the developing countries of Africa. While rising agricultural yields and rural out-migration have allowed forests to revert in the richer countries of the temperate world, the poor countries of tropical Africa are fast depleting their forest resources. As estimates indicate, by the early 1990s, the rate of deforestation in this part of the globe was about 29 times the rate of afforestation and/or reforestation (Salih, 1992). If this trend continues, then it would not be too long before forests will be completely removed from the African landscape. One of the main deriving forces of the deforestation in these developing countries is the pressure that growing population use forests for fuelwood for domestic energy production purposes (Boahene, 1998). Deforestation has, as is widely recognised, manifold environmental consequences: loss of biodiversity and genetic resources, soil degradation, depletion of water resources, disturbance of microclimates, loss of wildlife resources, and impediment to the cycling of carbon to mention a few. Some of these effects are more local while others are global.

In Ethiopia, like in many other developing countries, there is a heavy dependence on fuelwood in particular, and the traditional biofuel sources in general, in both the urban and rural areas. In urban areas, the traditional biofuel sources contribute 80 per cent (56% fuelwood, 9% charcoal, 8% dung and 7% crop residues) of the total household energy consumption, while modern sources account for 20 per cent (15% kerosene and LPG, 0.3% diesel, 4.7% electricity). In the rural areas of the country, where more than 85% of the total population lives, the traditional fuel sources contribute 99.9% of the total energy consumption, which is constituted of 81.9% fuelwood, 9.3% cattle dung, 8.3% crop residues and 0.4% charcoal. The share of modern fuels is insignificant (0.1%), which is kerosene and diesel mainly used for lighting purposes (Mekonnen, 1997). Though the country has considerable potential for both subsurface (coal and natural gas) and renewable (primary solar radiation, hydropower and wind) energy resources, these have been largely untapped. For example, the annual hydroelectric power production is currently only 1480 GWh per annum, while the potential is estimated at 159,300 GWh (TGE, 1992; FDRE, 1997; Solomon, 1998).

As mentioned in various studies, this extreme dependence on fuelwood has been a major factor leading to the high rate of deforestation Ethiopia has experienced. As estimated by Aklog (1990), for instance, some 87% (i.e. ~47 million ha) of the highlands (>1500m) of the country was originally under climax forest cover. However, by the beginning of the 1990s, much of this forest had been cleared and the estimated areal coverage of natural forests was only around 2.3 million ha (EFAP, 1993). The EFAP (1993) also reported an alarming rate of deforestation: between 150,000 and 200,000 ha yr^{-1}. Similarly, the WRI (1990) estimated deforestation to be proceeding at the rate of 88,000 ha yr^{-1}, while reforestation was estimated at only 13,000 ha yr^{-1}. The big difference between the estimates of deforestation is simply because much of the information is derived from indirect sources such as previous reports which were based on travellers' accounts and observation of remnant trees and seldom, if at all, from quantitative empirical studies. Contrary to these and other studies that estimate the rate of deforestation to be excessively high (e.g. Davidson, 1988; IUCN, 1990), time series analysis of remotely sensed images revealed a slightly increased forest cover in the Chemoga watershed during the past 40 years (Woldeamlak, 2002). This increased forest cover of the watershed was ascribed partly to household level planting of trees, particularly eucalypts, dictated by the growing scarcity of wood for fuel.

Though there is some literature on the forest resources of Ethiopia, as cited above, and a few studies on domestic energy consumption patterns in urban areas of the country (e.g. Denkneh, 1984; Kebede, 2000), the emphasis has been only on the deforestation caused mainly by the rural households. On the other hand, investigations about the rural households' biofuel consumption patterns and tree planting and management practices, as a response to the scarcity of fuelwood, are rather scanty. Such studies are needed to design appropriate strategies and policies for the development of the energy sector as well as for environmental management. The aim of the present study was; therefore, to investigate in some detail household level tree planting practices with reference to biofuel consumption patterns in a typical watershed in the northwestern highlands of Ethiopia. The specific objectives of the paper were to: (i) assess biofuel consumption patterns in the rural households; (ii) examine the relationship between some socioeconomic factors and biofuel consumption of households and (iii) investigate households' tree planting practices.

Study area- Chemoga watershed

The Chemoga watershed lies within $10^0$18'N to $10^0$39'N and $37^0$44'E to $37^0$53'E. In administrative terms, it is located in Gozamen woreda (district), East Gojjam zone, Amhara Regional State. The watershed is located at some 300 km northwest of Addis Ababa, and forms part of the northwestern highlands of Ethiopia. According to the simplified traditional agroclimatic classification system, which considers only temperature and altitude, the watershed lies within *dega* (temperate) and *wurch* (alpine) zones. The climatic condition is generally humid. As measured at Debre-Markos ($10^0$20'N, $37^0$40'E and elevation 2411m), mean annual temperature is 14.5^{0}C with a range from 13.2^{0}C in July and August to 17.3^{0}C in March, and mean annual rainfall is 1300 mm. More than 75% of the total rain falls in the four months of June to September (*kiremt* season). The dry months are October to February (*bega* season), when less than 5% of the annual total rainfall occurs. Since the watershed lies at a higher elevation (between 2420 and 4000m) than Debre-Markos, temperatures are lower and rainfall probably higher than these values. The total area of the watershed is 364 km^2, and the total population is 40,768, according to the rural population density (112 persons/km^2) estimation for the Gozamen woreda (Gozamen Woreda Office of Agriculture, 2001). This population density is slightly higher than the average for the Amhara Regional State (99.6 persons/km^2) and much higher than the national average (49.3 persons/km^2) (NOP, 1999).

The farming system is a typical mixed crop-livestock system that is carried on a subsistence scale. Land and livestock are therefore the most important assets of the people, with which they lead a sedentary life. Livestock provide the draught power and household members the labour that is needed for the farming operation. A variety of crops are produced by a household because of the strong orientation towards self-sufficiency. Barley (*Hordeum vulgare*), Wheat (*Triticum vulgare*), oats (*Avena sativa*), horse beans (*Vicia faba*), potato (*Solanum tuberosum*) and onion (*Allium cepa*) are grown in the upstream part of the watershed; and *tef* (*Eragrostis tef*) is additionally cultivated in the downstream part. Crop production is the major source of income to the households. Incomes from off-farm employment, where the definition of off-farm employment included all activities outside of one's own farm: working on another farmer's farm, petty trading, weaving, carpentry, smithing and pottery, are scanty (Woldeamlak, 2001).

Data and methods

The data for this study came from a structured household survey conducted between March and May 2000. The procedure of household surveying was as follows. First, four sample villages, the lowest tiers in the administrative structuring of Ethiopia, were selected on purpose to cover the upstream, midstream and downstream reaches of the study watershed (Table 1). Then, lists of households in each of the villages were obtained from the respective administrations. With the lists, a systematic random sampling procedure was used to select a total of 133 sample households. In cases where a selected household head happened to be away from home for a long period, or unwilling to be interviewed, a randomly selected substitute was included. The interview was conducted by going to each sample household's homestead.

Table 1. The four sample villages in the Chemoga watershed, Ethiopia

Study village	Position in the watershed	General elevation (m)	Climatic zone	Total N^o. of households	Sample size[a]	Average household size
Dangule	Upstream	3200-3800	Alpine	1121	38	6.0
Sinan	Upstream	2800-3200	Temperate	868	31	6.6
Keny	Midstream	2600-3000	Temperate	909	32	6.2
Yegagna	Downstream	2450-2600	Temperate	772	32	6.3

[a]Sample sizes varied between villages due to differences in their geographical areas and total No. of households.

It was known previously that fuelwood and cattle dung were the most important biofuels used by households in the study region. Hence, the survey included questions about the quantity of these biofuels used for domestic purposes, sources of the biofuels, distances travelled to sources and on perceptions of interviewees about shortages of fuel sources and their responses to the shortages. As it was impractical to ask for the weight of wood and dung consumed, interviewees were asked to mention the number of bundles of wood and baskets (*kirchat*) of dung they used per week. The size of bundles of wood varies depending on the tree species and the physique of the person carrying it. Also, the size of baskets varies; and depending on the size and pattern of stacking the dung cakes, the weight of a basket of dung also varies. Therefore, an attempt was made to determine the mean weight of a bundle of dry wood and a basket of dry dung. The average weight of a bundle of wood and a basket of dung was 12.5 kg and 6 kg, respectively. Both men and women were involved in estimating the quantities of fuelwood and cattle dung consumed per week, while mostly men answered the other questions on household socio-economic aspects that were asked. The estimations given were average consumption for the dry and rainy seasons.

Some households were found to use crop residues such as maize stalks as fuel sources mostly during the dry season. However, the amount was insignificant as such crops are not thriving well in the study villages. Also, crop residues are more often used as animal feed than for energy production. Therefore, crop residues as biofuel were not included in this paper. Use of charcoal is virtually unknown to the study population, because the acacia trees that are commonly used for charcoal production are not widely available in the area. Regarding the number of trees planted, interviewees were asked to count and report the number and types of their trees. The survey also generated socio-economic data on household sizes, landholdings, incomes from crop production, off-farm sources and sale of wood and trees and cattle ownership. Statistical analyses (descriptive, correlation, ANOVA and least significant difference (LSD) test) were done using SPSS release 10.

Biofuel consumption in the sample villages

Fuelwood

Fuelwood consumption among the surveyed households ranged from 0 (for those who depend entirely on cattle dung) to 6500 kg yr^{-1}, with the largest number of households using about 1300 kg yr^{-1}. The average consumption was 2252 kg yr^{-1}, and 36% of the households consumed more than the average. The annual total fuelwood consumption for all the households (133) included in the survey was 284 metric tons (~567 m^3), with significantly different ($F = 8.5$, $P = 000$) mean annual quantities of 2405 kg yr^{-1} for Dangule (upstream), 2710 kg yr^{-1} for Keny (midstream), 2450 kg yr^{-1} for Sinan (upstream) and 1300 kg yr^{-1} for Yegagna (downstream) (Table 2). The annual fuelwood consumption in Yegagna was significantly lower than in the other villages, as indicated by the LSD test, and can be attributed to differences in the microclimatic conditions of the villages, availability of wood supply from natural vegetation resources, and ownership of privately planted trees. Due to its lower elevation, energy use for heating was considerably lower in Yegagna. Unexpectedly, total biofuel consumption and fuelwood consumption were not the highest in Dangule, which has the coldest climate. Thus, households tend to reduce consumption when availability is low, suggesting lower frequency of well cooked meals. This contrasts with other studies which argue that household level energy consumption is not reduced by supply shortages (e.g. Dewees, 1995).

Table 2. Annual estimated fuelwood consumption in the four villages in Chemoga watershed, Ethiopia

	Percentage of households per village			
Fuelwood consumption (kg yr^{-1})	Dangule	Sinan	Keny	Yegagna
≤ 1950	55.3	61.3	46.9	78.1
1951-3900	36.8	22.6	28.1	3.1
3901-5850	5.3	12.9	15.6	3.1
≥5851	2.6	3.2	3.1	-

Natural forests and woodlands, which have become very scarce, are important sources of fuelwood to households in Dangule (Fig. 1). These natural sources provided the only source of fuelwood to 32% of the surveyed households in this village, while the corresponding figures were 6% in Sinan and nil in the others. In addition to the local climatic condition and virtual absence of natural vegetation cover, fuelwood consumption in Yegagna is also affected by its location close to the town of Debre-Markos. This is because the demand for fuelwood and construction timber by the town's population has made privately planted trees important sources of cash, and has led to a decreased domestic consumption of fuelwood and encouraged a shift towards use of more cattle dung.

Figure 1. Remnant natural forest cover in the upstream part of the Chemoga watershed.

Commonly taken as a proxy for fuelwood scarcity and deforestation are distances travelled and time spent by households to collect fuelwood. The assumption is that with deforestation, people are forced to spend a considerable part of their time collecting fuelwood from the receding forests and woodlands. This is expected to have important implications on the time spent in agricultural production. As a rough indicator of changes in fuelwood supply, the sample households were asked to assess the average time spent travelling to collect fuelwood 20-30 years ago and at the present (Table 3). These estimates need to be inspected with caution as they may not be very accurate.

Table 3. Comparison between current and past (1970-80) distances travelled to fuelwood sources (average for *bega* and *kiremt* seasons) in the four villages in Chemoga watershed, Ethiopia

Distances in minutes	Percentage of households per village							
	Dangule		Sinan		Keny		Yegagna	
	Past	Present	Past	Present	Past	Present	Past	Present
≤ 30	65.8	42.1	41.9	83.9	59.4	93.7	46.9	96.9
30-60	21.1	34.2	22.6	16.1	28.1	3.1	37.5	3.1
60-90	7.9	13.2	3.2	-	12.5	3.1	9.4	-
90-120	5.3	7.9	16.1	-	-	-	3.1	-
≥ 120	-	2.6	16.1	-	-	-	3.1	-

The average return journey 20- 30 years ago was estimated to take 96 minutes. At 5 km hr^{-1}, the distance to the fuelwood sources was therefore about 4 km. Currently, the equivalent journey takes about 38 minutes, which is equivalent to 1.6 km, as a result of tree planting for fuelwood. Privately planted trees currently constitute the only source of domestic energy for 26%, 72%, 52% and 62% of the respondents in Dangule, Keny, Sinan and Yegagna, respectively.

Interestingly, the longest distance travelled to fuelwood sources was in the upstream village of Dangule. This is because a considerable number of households in this village are still dependent on natural vegetation resources. In the other villages, very few people travelled far to collect fuelwood because deforestation is nearly complete and it is very difficult to get fuelwood anywhere. According to the majority of respondents (78% of total), natural vegetation cover has decreased by more than 75% over the last three to four decades, mainly due to population growth, the associated demand for cropland, settlement land, construction wood and fuelwood. Currently there are a few households who are still totally dependent on natural vegetation resources for fuel. This will result in a further clearance of the little remaining natural vegetation.

Dung fuel

Dung represents the second largest source of domestic energy in the study villages (Table 4). The total quantity of dung used by the sample households was 142,740 kg yr^{-1}. Thus dung accounts for 34% of the total biofuel consumption of the surveyed households. This is much higher than the value given in Mekonnen (1997) as the national average (9.3%). Use of dung as fuel amongst the surveyed households ranged from 156 to 4680 kg yr^{-1}, with an average of 1107 kg yr^{-1}. The majority of households used 624 kg yr^{-1}, which is much less than the average. On the other hand, annual dung consumption of some 25% of the households was more than 1250 kg yr^{-1}. Variation in the annual dung consumption among the study villages can be attributed to differences in microclimatic conditions of the villages, availability of natural or planted fuelwood and the availability of dung itself. In Yegagna where the average number of cattle owned by households was the highest, use of dung was also the highest. Similarly, in Dangule where cattle ownership was higher than the other two villages dung use was also high. However, the differences between the four villages were not statistically significant.

Table 4. Annual estimated dung use in the four villages in Chemoga watershed, Ethiopia

Dung use (kg yr^{-1})	Percentage of households per village			
	Dangule	Sinan	Keny	Yegagna
≤ 936	68.4	61.3	53.1	59.4
937-1872	21.1	32.3	34.4	21.9
1873-2808	5.3	3.2	6.3	15.6
2809-3744	-	3.2	6.3	-
≥ 3745	5.3	-	-	3.1

The use of dung as fuel is at the opportunity cost of using it as organic fertiliser. Cow dung contains essential plant nutrients with average dry matter composition of 1.46% N and 1.30% P by weight, and 5.7 kg K and 1.4 kg Ca per ton of dry dung (Newcomb, 1984). Thus, 32 tons of dry manure contains the N equivalent of one ton of Urea. The N and P content of dry dung is in proportions roughly equivalent to that of Diammonium Phosphate (DAP). Thus, one ton of DAP roughly equals 16 tons of dry dung.

The total dung burnt by all the sample households was 142,740 kg yr^{-1}. Using this amount of dung as organic fertiliser would add N and P into the soil system which will be equivalent to applying 9 tons of DAP. Similarly, the N added would be equivalent to applying 4.5 tons of Urea.

Dung also contains micronutrients such as Iron, Sulphur, Magnesium, Boron, Manganese, Cobalt, Zinc and Molybdenum. Using dung as a fuel source instead of as an organic fertiliser therefore has important implications on both the households' and the national economy, as chemical fertilisers are imported inputs. Furthermore, using only chemical fertilisers has negative effects on soil structure (Morgan, 1995). Soils with poor structure are more erodible, less aerated and less productive. Farmers are well aware of the value of dung as organic fertilizer. The principal reason for using it as a fuel source instead is that fuelwood is in short supply (84% of respondents). Other reasons included the difficulty of spreading dung over fields (8% of total respondents) and the ease of burning it (6% of total respondents).

Dung is procured both from privately owned cattle and collected in the surroundings, including communally held grazing lands and privately operated cultivated fields which turn into a common property resource for grazing after harvesting the crops. Women and children do the collection of dung, while fuelwood collection is an activity of all members of a household. Collection is carried out in the dry season and part is stored for use in the rainy season (Fig. 2). Dung constitutes the only source of domestic energy for households with a shortage of labour to collect wood or to plant their own trees. In addition to domestic use, some low-income households, particularly female-headed ones, sell dung cakes in nearby towns of Rob-Gebeya (to Dangule and Sinan), Yebokila (to Keny) and Debre-Markos (to Yegagna) to generate some cash income. The average price in Ethiopian Birr is 2.00 (~0.24 $US, June 2001) per basket. Dung collection from grazing lands and harvested fields is accessible to any one including those who have no plot of land or cattle. This indicates that such common property resources must not be privatised as they are important sources of livelihood for the rural poor without alternative sources of income.

Figure 2. Cattle dung collected during the dry season and stored surrounding a house for use during the rainy season, the Chemoga watershed.

Biofuel consumption and household socioeconomic characteristics

Total biofuel consumption of the surveyed households ranged from 962 to 8,918 kg yr^{-1}, and the mean per capita consumption was estimated at 511 kg yr^{-1}. This is lower than the national average estimated at 2.1 kg per person per day (TGE, 1992). Both total and per capita biofuel consumption showed the same pattern across the villages (Table 5), being lowest in Yegagna and highest in Keny. The differences between the four villages were statistically significant ($F = 3.90$, $P = 0.011$); biofuel consumption in Yegagna being significantly lower than that in the other villages (as indicated by the LSD test). These variations are attributable to differences in their local climates and the availability of biofuel.

Table 5. Average estimated annual biofuel consumption in the four villages in Chemoga watershed, Ethiopia

	Fuelwood		Dung		Total biofuel	Per capita
	kg	% of total	kg	% of total	(kg)	biofuel (kg)
Dangule	2405	68.3	1118	31.7	3523	587
Sinan	2451	70.2	1042	29.8	3492	529
Keny	2711	71.7	1071	28.3	3782	610
Yegagna	1300	52.2	1190	47.8	2489	395

Household level variations in biofuel consumption were also discernible in each of the villages. These were indicated by the coefficients of variations of 47% in Dangule, 58% in Keny, 52% in Sinan and 63% in Yegagna. These variations represent variation in socioeconomic factors influencing the quantity of biofuels consumed by households. Household size was not, however, significantly correlated with fuelwood use (Table 6), and this indicates absence of considerable economies of scale in fuelwood consumption when using the traditional three-stone stoves. Likewise, there was no significant association between household size and dung consumption, suggesting that larger households which possibly have the labour required for dung collection do not use a different quantity of dung.

The association between biofuel use and income from crop production was not statistically significant. On the other hand, off-farm income (which was defined to include any income from working on another farmer's farm, petty trading, weaving, carpentry, smithing and pottery) and fuelwood use were positively correlated ($r = 0.267$, $P<0.01$). The explanation may be that households engaged in off-farm activities have smaller landholdings to be engaged full-time in crop production; thus having some time to spend on fuelwood collection. Interestingly, there was a negative correlation between fuelwood use and cattle ownership, which was statistically significant ($r = -0.248$, $P<0.01$). Thus, more dung, but less fuelwood, is consumed by households with larger numbers of livestock. This suggests that in rural Ethiopia livestock ownership plays an important role in the domestic energy supply and consumption. Additionally, the possibility of using a larger proportion of dung as organic fertiliser by households with larger livestock numbers is constrained by its increased use as fuel as wood gets scarcer.

Table 6. Correlation matrix showing relationship between socioeconomic characteristics of households and biofuel consumption in the four villages in Chemoga watershed, Ethiopia

	Fuelwood	Dung	Total biofuel
Household size	- 0.06	0.14	0.01
Land holding	0.01	0.11	0.05
Income from crops	- 0.12	0.01	- 0.09
Cattle ownership	- 0.25[b]	0.03	- 0.18[a]
Off-farm income	0.27[b]	0.06	0.24[b]
Income from sale of wood	0.16	0.02	0.14
Number of trees planted	- 0.02	- 0.01	- 0.02

[a]significant at 0.05 level; [b]significant at 0.01 level

The association between fuelwood use and number of trees planted was not statistically significant; and similarly, the correlation between number of trees planted and use of dung as fuel source was not significant. This implies that households prefer to obtain some cash income from sale of wood and trees, and to use more of cattle dung as a source of fuel. Thus, the chance of diverting use of dung as a soil conditioner instead of fuel source is constrained by the poverty of the people. Even when the sample households were classified into three wealth categories: rich, medium and poor (Table 7) based on their annual gross incomes, it was found that no two groups were significantly different in terms of fuelwood, cattle dung or total biofuel consumption, although the differences in the income levels were significant ($F = 424.47$, $P < 0.001$); all the three groups significantly differing from each other (LSD test).

Table 7. Average estimated annual biofuel consumption by income groups in the four villages in Chemoga watershed, Ethiopia

Income group	Number of households	Average income (Birr[a])	Fuelwood (kg)	Dung (kg)	Total biofuel (kg)	No. of trees planted
Rich	24	2518	2302	1209	3511	454
Medium	52	1363	2100	978	3078	361
Poor	57	657	2092	1103	3195	162

[a]8.34 Birr ~ 1.00 $US, June 2001.

Household level tree planting: a commendable response to scarcity

Among the surveyed households, number of privately planted trees ranged from 0 to more than 2,500 (Table 8), with significant differences between the four villages ($F = 3.28$, $P = 0.028$). This tree planting operation at the farm level has contributed for the slightly increased forest cover of the watershed over the last four decades (Woldeamlak, 2002), although there is a difference between natural forest cover and planted trees. The total number of trees planted by all the households was 38,050, with an average of 307 trees per household. The average number of trees planted per household was lowest in the upstream village, Dangule (95 trees). This is attributable to the presence of some natural vegetation cover, used as a fuel source, and the harsh environmental conditions (limiting temperatures) for tree growing. On the other side, average tree holdings per household were the highest in the downstream village, Yegagna (418 trees), due to the more favourable environmental conditions to grow trees, larger per capita landholdings, and proximity of the village to the town of Debre-Markos, a potential market for fuelwood and timber.

Eucalyptus was the tree species grown prevalently and was the only species planted by 80% of those households who have planted trees. The reason given for preferring eucalypts was its fast growth and resistance to various environmental factors. The trees are planted around homesteads, farm boundaries, along roads and footpaths, inside gullies and along gully sides, and in some cases, in formerly cultivated or grazing fields where they are grown in larger blocks (Fig. 3). In the case of the last, establishment of the eucalypt trees appears to be the last in an agro-ecological succession of land use types in the area, suggesting that eucalypts have been planted in areas too degraded for crop production. On the other hand, most of the respondents expressed concern, that the eucalypt trees have negative ecological effects due to its water use. This observation conforms with general experience (FAO, 1988). Despite its negative ecological externalities, which need to be verified further, eucalypt trees can improve farmers' livelihoods by contributing to diversifying farming systems and raising farm incomes and thereby increasing food security, particularly in 'less favoured' areas of Ethiopia (Jagger and Pender, 2000). Nevertheless, introduction of seedlings of multipurpose trees that can supply wood, fodder and improve soil fertility will be meritorious.

Table 8. Number of trees planted in the four villages in Chemoga watershed, Ethiopia

Number of trees planted	Percentage of households per village			
	Dangule	Sinan	Keny	Yegagna
0	13.2	9.7	-	3.1
1-50	42.1	3.2	18.8	15.6
51-150	34.2	38.7	15.6	28.1
151-250	5.3	9.7	25.0	21.9
251-350	2.6	16.1	9.4	3.1
351-450	-	3.1	12.5	6.3
451-550	2.6	9.7	6.3	3.1
≥ 551	-	9.7	12.5	18.8

Privately planted trees go a long way to meeting the need of households' for fuelwood. Nearly 45% of the total respondents estimated that between 75 and 100% of their demand for fuelwood was met by privately planted trees; while a further 20% indicated that these trees met 50-75% of their fuelwood needs. For the remaining households less than 50% of their energy demand was met from planted trees, while 10% indicated that they were fully dependent on other sources of fuel. The latter group included those who had not planted any trees and those whose trees were not yet grown to sizes big enough to be cut and used. The majority of respondents (84%) stated that fuelwood is in short supply in their communities, and is growing scarce. More than 70% of the respondents saw planting of their own trees as a solution, although a few mentioned alternative sources of energy such as kerosene and electricity. This finding suggests that, unlike much of the literature on the forest resources of Ethiopia that simply assume the rural households to be agents of deforestation, the tree planting and management activities of these households should also be appreciated. Similar findings, that rural households play important roles in tree planting and management, were reported by research works undertaken in rural communities elsewhere in Africa (FAO, 1990; Kajembe, 1994; Price and Campbell, 1998).

When the relationships between tree planting and some socioeconomic characteristics of households were analysed, the results indicated that there is a positive relationship between number of trees planted and literacy of household heads (r = 0.286, P<0.01). That is, literate farmers (at least able to read and write) are more motivated to plant their own trees than their illiterate counterparts. The association between number of trees planted and size of landholdings was not significant. This is simply because younger households with smaller landholdings are also planting trees while larger landholdings are in the hands of the elderly. The latter is shown by the statistically significant positive correlation between ages of household heads and sizes of land held (r = 0.271, P<0.01); and the negative association between ages of household heads and number of trees planted (r = - 0.267, P<0.01).

Figure 3. Eucalypt trees planted by farmers around their houses, the Chemoga watershed.

Evidence was not found in support of the intuitive assumption that households having smaller landholdings would focus on producing annual food crops, as the shortage of wood for fuel and construction purposes has encouraged the younger generation to plant their own trees. As these young households, who have smaller family sizes than older ones, are planting trees, the association between household size and number of trees planted was not significant. This implies that labour was not a constraining factor to tree planting for most of the households. The number of trees planted and number of cattle owned was positively correlated (r = 0.196, P<0.05), suggesting that possession of a larger source of dung fuel does not negatively affect households' decisions on planting trees. Instead, richer households tend to plant more trees than the poorer ones possibly because the fuel and construction wood demand of better-off households is greater. This is reinforced by the positive association between number of trees planted and income from crop production (r = 0.121), and income from sale of livestock and livestock products (r = 0.230, P<0.05). The difference between the three income groups in terms of the numbers of trees they planted was significant (F = 4.24, P = 0.016); those owned by the poor being significantly smaller than the rich and medium groups of farmers (LSD test).

There were a few households who had not planted any trees. These groups entirely depended on natural vegetation resources including low quality shrubs and roots, cattle dung and purchases of fuelwood from others. These non-planters indicated that the reasons were the small size (or lack) of their plots of land, harsh environmental conditions to grow trees, shortage of labour and insecure tree/ land tenure. The feeling of insecurity on tree/ land tenure emanates from the state ownership of the land. Land has been under state ownership in Ethiopia since the 1975 national land reform, and there have been many redistributions and readjustments since then. The last readjustment in the study region (Amhara Regional State) was conducted in 1997.

Conclusions

As in any developing country, the demand for energy in Ethiopia is largely for subsistence and is met mainly from biofuels. With the growing human population and shrinking natural vegetation resources, planting trees on privately held land is an option towards future energy security of the rural population of Ethiopia and can also have multiple positive economic and environmental effects. It can help to reverse the trend of deforestation and consequent ecological degradation and the saved time from being spent on fuelwood and dung collection can be used for productive agricultural activities. In addition, the use of dung as an organic fertilizer can be enhanced, saving hard currency from being spent on chemical fertilisers. Hence, tree planting on private and community lands unfit for agriculture should be promoted as a short-term fuelwood strategy and for environmental conservation in rural Ethiopia.

At present, eucalyptus is the tree species dominantly grown; and it has negative ecological effects and cannot be fed to livestock, as expressed by the majority of the surveyed households themselves. In addition, the trees are planted mainly around homesteads and in lands which are limited in extent. Integration of trees with crops in cultivated fields, i.e., agroforestry, for multiple purposes such as for wood requirements, livestock fodder, soil fertility improvement and soil and water conservation should therefore be advanced. In promoting household and community level tree planting, (agro)foresters and environmental conservation planners and aid agencies working on environmental rehabilitation and management activities in the country should take into account local level biophysical and socioeconomic realities. This helps to select tree species that will meet the needs of the people and thrive best under given environmental conditions and to identify socioeconomic factors that will affect households' decisions whether to plant trees. The issue of security on tree/ land tenure is also important. It was one of the reasons given by the non-planters for not having planted trees. Farmers with insecure landholding will only think in subsistence terms, as it would be risky to undertake planting without a secure tenure. Policies are therefore needed that confer secure rights on trees/ land to promote household level tree planting and sustainable resource management.

Finally, household and community level (agro)forestry practices have environmental implications transcending the local scale, as consequences of degradation know no political boundaries. For instance, the fact that farm level tree planting helps to reverse the destruction of natural forests and increases vegetative land covers has global environmental implications such as on the preservation of biodiversity and genetic resources and the carbon cycle. These global environmental roles of local level afforestation (or deforestation) activities are currently acknowledged as off-site effects of land cover dynamics (IGBP, 2001). Given this international significance and the fact that Ethiopia is a developing country with complex problems of underdevelopment, much assistance will be expected from the international community for afforestation or reforestation, and environmental rehabilitation activities in general. Local people's solutions to local environmental and socioeconomic problems, such as the household level tree planting practices reported in this paper that are based on their intimate understanding of local situations, can be used as points of entry by international aid agencies to bring about grassroots-based and sustainable environmental management and socioeconomic development in the country.

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Chapter 8

Farmers' participation in soil and water conservation activities in the Chemoga watershed, Blue Nile basin, Ethiopia

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Farmers' participation in soil and water conservation activities in the Chemoga watershed, Blue Nile basin, Ethiopia

Abstract

Soil erosion by water constitutes a threat to the maintenance of the subsistence living of the Ethiopian rural population. Past efforts at soil and water conservation (SWC) did not bring about significant results, mainly because of the top-down approach pursued. Uprooting this past oversight and instating a participatory approach has since then been strongly recommended as the correct strategy. This paper analyses the extent of farmers' participation in current SWC activities in the Chemoga watershed, East Gojjam Zone, Amhara Regional State. Formal household survey, informal and focus group discussions and field observation were used to generate the data. The results indicate that the majority of the farmers participated in the SWC against their will. The most important factor discouraging them from participating freely was the perceived ineffectiveness of the structures under construction. Awareness about soil erosion as a problem, labour shortage, and land tenure insecurity were found to be less important in providing explanation for the disinterest shown by most of the farmers towards the SWC activities. Therefore, the important factors that need immediate consideration for SWC efforts in the study area or the region at large are: (i) SWC structures have to be carefully designed and constructed taking into account ground realities, and (ii) participation of the farmers has to be through their own conviction regarding the effectiveness and efficiency of the technologies. Alternative SWC technologies will have to be considered in this regard.

Key words: erosion; soil and water conservation; participation; Ethiopia

Introduction

In Ethiopia, the population pressure on land is evident from the disproportionately high contribution of the agricultural sector. It accounts for 80% of employment, 85% of the export revenue and 45% of the GDP (FDRE, 1997). Much of the pressure is found in the highlands above 1500m (~45% of the country's total area), where some 88% of the human and 75% of the livestock populations are accommodated and about 95% of the regularly cultivated lands are situated (FAO, 1986). These highlands, which are characterised by favourable environmental conditions, have been settled for millennia and agriculture, which is until today exploitative, has a matching history. This pressure, coupled with many other physical, socioeconomic and political factors, has led to a serious degradation of the land. According to El-Swaify and Hurni (1996), the Ethiopian highlands presently constitute one of the most degraded lands in Africa. Among the forms of land degradation, soil erosion by water is the biggest problem. As estimates from a national scale study indicate, average soil removal all over the country is about 2 billion tons per year; and on cropped lands, annual average soil loss is about 100 tha^{-1} (FAO, 1986). With these rates, the study predicted, soil erosion would have reduced per capita incomes of the highlands' population by about 30% by the year 2010.

Soil erosion was recognized to be a serious problem to the country subsequent to the change of government and the droughts and famines of the early 1970s. With regard to the traumatic drought and famine incidence, the national government and the international donor community identified land degradation as the underlying cause. The degradation of the land was, in turn, attributed to the subsistence-oriented farmers' reckless resource use practices, which included clearing steeplands of vegetative covers in the quest for fuelwood and cropland and the misuse of the cultivated lands without putting in place the necessary conservation measures (Markos, 1997; Yeraswork, 2000). The assumed cause of land degradation provided the logical reason for urgent action to be taken to halt land degradation and rehabilitate degraded environments through an extensive SWC program by mobilizing the farmers. This had critical implications on the way the program was to be implemented. The government mobilized the farmers for campaign work through their respective peasant associations; and when the emergency situation was over, some of the aid organizations redirected their support towards the conservation activities by providing farmers with food-for-work payments using food grains and edible oil that was meant for the relief assistance. The emphasis was on mechanical conservation measures, most of which were alien and foreign to the farmers. The farmers were virtually considered ignorant of SWC and were excluded from the planning of and commenting on those engineering solutions (Azene, 2001).

This national effort, combined with the huge assistance from the international aid agencies, resulted in achievements that were described as 'impressive' (Daniel, 1988; Wood, 1990; Scoones, *et al.*, 1996). For instance, between 1976 and 1988, some 800,000km of soil and stone bunds and 600,000km of terraces were constructed; about 500 million tree seedlings were planted; about 100,000ha of land were closed for natural regeneration and check dams were constructed along gullies over tens of thousands of kilometre (Wood, 1990). However, those achievements were later evaluated as only quantitative with minimal desirable outcomes and ineffective and unsustainable (Yeraswork, 2000). The whole effort was, therefore, eminently a failure. Several factors have been identified as reasons for the failure. The most important of all is said to be the top-down approach pursued in the planning and implementation processes (Stahl, 1990; Million, 1996; Scoones, *et al*., 1996; Azene, 1997, 2001; Yeraswork, 2000). In recognition of this experience, a new approach that ensures a genuine involvement of the people directly involved is presently widely recommended to tackle the problem of soil erosion, which has remained critical to the national economy. This is also enshrined in the environmental policy document of the country (FDRE, 1997). Nevertheless, it is rarely seen being put into practice. In fact, insufficient attention has been given to examining local level factors on which participation of the stakeholders will depend and to decide precisely what a participatory approach really does mean.

The main objective of this study was to investigate the extent of farmers' participation in current SWC undertakings in the Chemoga watershed, Blue Nile basin. The specific objectives were to: (i) verify whether farmers' participation in the SWC activities was due to their own conviction, and (ii) identify and describe major factors influencing farmers' willingness to participate in the SWC activities. The study specifically focused on the SWC works that were underway by the time of the fieldwork (1999-2000). The conservation endeavour was claimed to be farmer-centred and participatory by the local office of the agriculture ministry, which was superintending the implementation.

Materials and methods

Site information

The study was conducted in the Chemoga watershed, which lies within $10^{0}18$'N to $10^{0}39$'N and $37^{0}44$'E to $37^{0}53$'E in the Blue Nile basin. In administrative terms, it is located in Gozamen Woreda (district), East Gojjam Zone, Amhara Regional State. Having an area of about 364 km^2, around 40,768 people inhabit the watershed. In terms of topography, the watershed is characterised by diverse conditions. Elevation ranges from 2420m to nearly 4000m, and slopes range from nearly flat (<2%) to very steep (>55%). The upstream part is characterised by a mountainous and highly dissected terrain with steep slopes; and the downstream half is characterised by undulating topography and gentle slopes. The climatic condition is generally humid with mean annual temperature of 14.5^{0}C and mean annual rainfall of 1300 mm.

The farming system is a typical mixed crop-livestock system that is carried on a subsistence scale. Land and livestock are therefore the basic sources of livelihood to the farmers. Land has been under state ownership in Ethiopia since the 1975 national land reform, and there have been many redistributions and readjustments since then. The last readjustment in the study region (Amhara Regional State) was conducted in 1997. Many researchers believed that the frequent land reallocation has been a source of tenure insecurity and a disincentive for the farmers to invest in SWC works. A variety of crops are produced by a household because of the strong orientation towards self-sufficiency. Livestock provide the draught power and household members the labour that is needed for the farming operation. Livestock ownership is also used as a measure of wealth status of households, hence the social standing attached to the number of livestock owned regardless of economic value and the feed shortage. There is a serious shortage of animal feed in the area, as in much of the country. The livestock depend on degraded communal grazing lands and free roaming feeding of crop stubble in cultivated fields after the crops are harvested. By this traditional grazing system, two preconditions are created for soil erosion: removal of vegetative covers of the land and disturbance of the soil itself (Gete, 2000).

At the present, extent and pace of land degradation, particularly due to soil erosion, is distinguished as a serious threat to the viability of the subsistence agriculture in the Amhara Regional State (Lakew, *et al*., 2000). Accordingly, efforts are underway to rehabilitate degraded environments and stop degradation processes from continuing throughout the region. It is reported that afforestation of communally held hillsides unsuitable for agriculture, providing of tree seedlings to farmers for private planting, advising of farmers about agroforestry practices and establishing of SWC structures in cultivated fields are the major environmental management activities being undertaken. Of these, more emphasis is placed on implementation of mechanical SWC measures in cultivated fields (Lakew, 2000). It is being carried out as part of the extension package the government is employing as a strategy to achieve its five-year development program. The extension approach pursued is Participatory Demonstration and Training Extension System (PADETES). This approach has been adopted from the SG-2000 approach which came into being in Ethiopia in 1993 (Tesfaye, 1999). The PADETES is simply applying the classical top-down extension approach, commonly known as the transfer of technology (TOT) model. Its major activity is the transfer of technologies that are developed in experimental and research sites. This implies that the program lacks flexibility and adaptive characteristic to match with local biophysical and socioeconomic settings; and more importantly excludes the farmers from being involved in the process of technology generation and were therefore only on the receiving end. It is against this backdrop of PADETES that the SWC endeavour in the study area was claimed to be farmer-centred and participatory by the superintending institution.

Data sources and analysis

The major source of data was a formal household survey conducted between March and May 2000. The procedure of the survey was as follows. First, four sample villages were selected to cover the upstream, midstream and downstream reaches of the watershed (Table 1). Then, lists of households in each of the villages were obtained from the respective village leaders. With the lists, a systematic random sampling procedure was used to select a total of 133 sample households. In cases where a selected household happened to be away from home for a long time or was unwilling to be interviewed, a randomly selected substitute was included. Given the relative homogeneity of the subsistence farmers in the four villages in terms of physical environmental factors and resource endowments, the sample size of each village would be reasonably representative of the population it stood for. The interviews were conducted by going to each interviewee's homestead. The time taken by an interview ranged between 60 and 90 minutes. Early mornings and late afternoons were convenient times for the interviewees. Table 2 shows age and literacy profiles of the surveyed households in the four villages.

Table 1. The study villages in the Chemoga watershed

Study village	Relative position in the watershed	General elevation (m)	Climatic zone	Total N^{o}. of households	Sample size	Average HH size
Dangule	Upstream	3200-3800	Alpine	1121	38	6.0
Sinan	Upstream	2800-3200	Temperate	868	31	6.6
Keny	Midstream	2600-3000	Temperate	909	32	6.2
Yegagna	Downstream	2450-2600	Temperate	772	32	6.3

The second method of data collection was on-site discussion (informal) with individual farmers while they were constructing SWC structures. This informal dialogue provided a forum where farmers openly expressed their opinions and views with a feeling of being at an equal standing with the interviewer. Along with the on-site discussions with individual farmers, three focus group discussions were also held in each of the villages, with five to ten people in a group, using a checklist of topics to guide the sessions in an orderly way. Focus group discussion is generally believed to be powerful in eliminating exaggerated opinions that some individuals might express, as participants will be checked by each other. The major issues included in the questionnaires and raised during the focus group discussions were about the extent of the farmers' participation in the SWC activities in reference to their awareness and perception of erosion hazards, labour supply constraint, the land tenure system and the effectiveness of the technologies under implementation. The quantitative data analysis involved calculation of frequencies, descriptive and use of the chi-square statistic to test significance of relationships between farmers' willing participation in the SWC works on the one hand and their age, level of literacy, perception of erosion hazard, and size of land holding and labour supply and land tenure system constraints, on the other. The information generated through the informal and focus group discussions were used to substantiate and augment findings from the quantitative analysis of the structured questionnaires.

Table 2. Age and literacy profile of the surveyed households in the four villages- % of respondents

Age and Literacy of Respondent	Dangule	Keny	Sinan	Yegagna
Age of respondent				
≤ 25	2.6	3.1	6.5	3.1
26- 40	29.8	56.3	41.9	40.7
41-55	48.7	28.1	45.1	46.8
56- 70	16.2	12.5	3.2	9.4
≥ 71	2.6	-	3.2	-
Educational status of respondent				
Illiterate	60.5	43.8	22.6	43.8
Read and Write	36.8	46.9	61.3	53.1
Grade 1- 4	2.6	9.4	9.7	-
Grade 5- 8	-	-	3.2	3.1
Above grade 8	-	-	3.2	-

Results and discussion

Farmers' participation in the SWC works

In the Chemoga watershed, the major SWC work that we witnessed by the time of the fieldwork was construction of physical structures, mainly *fanya juu* bunds, in cultivated fields. A *fanya juu* bund, which is sometimes called a converse terrace, is constructed by digging a ditch and moving the excavated soil upslope to form an embankment to the ditch. The embankment is meant to trap runoff, sediment and nutrients above it, and the ditch is meant to collect any that will overtop the embankment. The ditch is thus providing protection to the part of the field in the downslope. Because of the interstructure transfer of soil materials, *fanya juu* bunds will eventually develop into outward sloping bench terraces. *Fanya juu* bunds are generally considered to be effective in areas with semiarid climates, too shallow soils to construct level bench terraces and moderately steep (<20%) slopes (Soil and water conservation branch, MoALDM, 1997). Construction of the *fanya juu* bunds is a highly labour-intensive task. In the study site, the farmers were doing the physical work, development agents (DAs) were working as 'facilitators' and the Gozamen Woreda Agricultural Office was working as superintendent. The conservation effort is truly meritorious, but only if it really is effective and can be sustainable. To be effective, it has to be carefully engineered; and to be sustainable, committed participation of the stakeholders- the farmers- is imperative. Hence the question: were the farmers willingly participating in the SWC works underway in their communities? Table 3 shows farmers' participation in the SWC activities in the study villages that were being carried out in 1999-2000.

Table 3. Farmers' participation in the SWC works- % of respondents

	Dangule	Keny	Sinan	Yegagna
How are you participating in the SWC works currently underway in your village?				
Voluntarily	38.7	40.6	34.5	43.8
Forced to participate	51.6	56.3	58.6	53.1
Not involved*	9.7	3.1	6.8	3.1

*This category includes those respondents who are exempted from working in the SWC works due to old age, or being women or clergymen.

As shown in Table 3, only 35-40% of the interviewed farmers participated in the SWC works voluntarily. The remainder, more than 50% of the householders, asserted that they participated simply because they were forced to do so by the village administration and the DAs. In the belief of many of the latter group, the *fanya juu* construction was not for the sake of conserving the farmers' soils and lands, but to meet demands of the government's five-year development program. With this circumstance where the majority felt coerced to participate, it becomes clear that the work did not take into account participatory principles. Why is it that the majority of the farmers were disinterested in the conservation works meant to improve or at least maintain productivity of their plots of land?

Awareness

As shown in Table 4, about 65% of all the farmers included in the survey acknowledged that erosion was a problem in at least one of their plots of land. Asked to mention signs with which erosion can be identified, the majority of the farmers rightly mentioned visible erosion features, rills, gullies and mass movements. But, again to the majority, it was learned during informal discussions, splash erosion and sheet wash are abstract processes. The chi-square analysis indicates that there is no significant relationship between educational status of respondents and perception of erosion as a problem ($\chi^2 = 0.199$, $p = 0.655$). Whereas, perception of erosion as a problem and age of respondents are significantly related ($\chi^2 = 10.337$, $p = 0.351$).

Regarding the causes of erosion, steep slopes and runoff from upslope were mentioned repeatedly by most of the respondents. A few also believed that the land has become more susceptible to erosion in recent years because of changes in the rainfall pattern. According to these farmers, the rainfall pattern has changed during the last 15 years. The duration of the dry season has significantly increased, while that of the rainy season has decreased. Today rains occur in a few weeks only, and usually in destructive storms. The farmers then reasoned that runoff easily sweeps down the soil that stays exposed to the hot sun over the long dry season. Asked what they thought was the reason for the change in the rainfall pattern, most of them mentioned deforestation as a probable cause. But, a few gave 'unique' reasons in connection to the most recent shortage of rain. According to the latter group, the rainfall regime was interfered with by sorcerers. Their suspicion was that, either there were some people in their villages who wanted to get money from the villagers by regulating the rain, or that the Ethiopian Roads Authority building roads around a small town of Yebokla (very close to Keny village) was controlling the rains until the construction would be finished. Wind was also mentioned as the other cause of soil erosion in the long dry season, but it was recognized only as it occurs in dust devils.

Table 4. Farmers' awareness of erosion and land degradation hazards- % of respondents

Erosion perception	Dangule	Keny	Sinan	Yegagna
Whether erosion was perceived as a problem in own farm				
Yes	60.5	87.5	54.8	56.3
No	36.8	12.5	45.2	43.8
Severity of the problem, if yes to the above question				
Severe	36.4	56.7	44.5	38.9
Moderate	54.5	26.7	50.0	50.0
Minor	9.1	13.3	5.6	11.1
Perception of trend in severity of erosion over the last 10 years				
Has become more severe	56.0	74.1	58.8	52.6
Has become less severe	44.0	22.2	41.2	47.4
Believing that erosion can be controlled				
Yes	97.1	90.3	93.5	96.8
No	2.9	9.7	6.5	3.2
Changes observed in fertility level of soils in own plots?				
Has been decreasing	92.1	96.9	96.8	96.9
No change	5.3	3.1	-	-
Don't know	2.6	-	3.2	3.1

Note: The percentages may not add up 100% because there were some respondents who gave different answers from the pre-enlisted ones.

The number of respondents mentioning erosion as a problem in their own plots of land was the largest in Keny (the midstream village), followed by that of Dangule (the upstream village). This is in line with what can be observed in the field. The visible erosion features, rills and gullies were very dense in Keny. Though the topography of the two villages is broadly similar, both to a large extent dissected, there is most probably a difference in the intensity of the rainfall. Dangule being at a higher elevation than Keny, the rainfall energy must be significantly lower, thus causing a less damage.

The majority of farmers confirmed that they observed an increasing trend in the severity of erosion and a decreasing trend in fertility of soils in their plots of land. However, the link between soil erosion and decline in soil fertility levels appeared to be unclear to them because the declining soil fertility was attributed to 'aging of the land' caused by overuse and not to erosion. Similarly, to the question whether livestock contribute to land degradation, 60% of the respondents firmly reacted 'no'. They believed that the contribution of livestock was rather to land fertility improvement. This implies that destocking will be a difficult alternative strategy to embark on for land management purposes. The farmers also seem not to realize that some of their own practices are the cause of soil erosion and land degradation. While they were eloquent in mentioning runoff caused by upslope land users, no one accepted that he/ she was also causing damage on his/ her own land as well as to a downslope land user.

In general terms, however, the responses of farmers were in agreement with what can be observed in the field that land degradation is a problem in the watershed. It can thus be concluded that farmers are well aware of the problems of soil erosion and land degradation. Also, the farmers generally believe that erosion can be controlled (94% of the respondents). Hence, their lack of interest in participating in the SWC activities cannot be explained by a lack of awareness about the problem. The chi-square analysis indicates that significant relationship does not exist between respondents' willing participation in the SWC works on the one hand and respondents' age (χ^2 = 2.039, p = 0.729), level of literacy (χ^2 = 1.708, p = 0.191), which can make a difference in awareness levels, and size of landholding (χ^2 = 0.131, p = 0.717) on the other.

Labour shortage

The majority of households in the Chemoga watershed have an adequate supply of labour that will be needed for the farming operation in their small holdings, including SWC works (Table 5). Some 53% of the total households have 4 to 6 members; and some 41% have 7 to 9 members. However, 56% of the households posses only 0.6 to 1.0 ha of land. Only 2.3% of them own more than 2 ha. Taking average household sizes and average land holdings of the villages, per capita holdings are 0.16 ha in Dangule, 0.19 ha in Keny, 0.13 ha in Sinan and 0.29 ha in Yegagna. This may somehow reflect the condition of the labour supply. More explicitly, the farmers were asked whether labour shortage was a problem in their farming activities. The answers reinforce what could be logically inferred from household size and land holding patterns. More than 72% of the farmers responded that labour supply was not a constraint in their farming operation. Hence, there is no plausible logic to assume that any of the farmers are disinterested in the SWC works principally because of the problem of labour shortage. The chi-square test also reveals that there is no statistically significant relationship between respondents' participation in the SWC works and their labour conditions (χ^2 = 3.660, p = 0.0557).

Table 5. Household size, landholding and labour condition of households- % of respondents

	Dangule	Keny	Sinan	Yegagna
Household size (number)				
≤ 3	5.3	6.3	-	-
4-6	57.9	50.0	45.2	59.4
7-9	34.2	40.6	51.6	40.6
≥10	2.6	3.1	3.2	-
Total land held (ha)				
≤ 0.5	15.8	6.3	16.1	15.6
0.6-1.0	55.3	50.0	74.2	43.8
1.1-1.5	13.2	25.0	6.5	25.0
1.6-2.0	10.5	12.5	3.2	9.4
>2.0	-	6.3	-	3.1
Labour shortage faced for own farm work				
Yes	26.3	31.3	32.3	15.6
No	73.7	68.7	67.7	84.4

The conclusions from the above two sections are in line with Osgood (1992), who states that research work on determinants of farmers' adoption of SWC technologies could find explanations to less than half of the variations in adoption rates from individual farmer characteristics such as age, level of education, family size and their farm characteristics such as size and distance from residence. According to the preceding sections of our study, correct perception of land degradation as a problem and labour availability are necessary but not sufficient conditions for farmers to willingly participate in the SWC activities.

Land tenure

Table 6 presents responses of the farmers to questions meant to assess the influence of security of land tenure on their decisions to invest in SWC works. As can be seen, the proportion of respondents opposed to absolute private ownership of land by present users is more than 84% of the total. Only the remainder are in favour of private ownership rights. To the question whether they expect land redistribution in the future, more than two-thirds of the respondents answered 'yes'. Those not expecting that to happen were less than 7% of the total, while the rest avoided giving any prophecy on the subject. About 14% of the respondents have lost plots that they held during the last (the 1997) redistribution, while 18% have gained additional plots. Those possessed by the majority of the respondents (about 61%) were not affected by the redistribution.

Table 6. Effect of the 1997 land redistribution on individual holdings and farmers' opinions on aspects of land tenure- % of respondents

	Dangule	Keny	Sinan	Yegagna
Should land be absolute private property of present holders				
Yes	31.6	6.3	12.9	12.9
No	68.4	93.8	87.1	87.1
Expecting land redistribution in the future				
Yes	65.8	68.8	77.4	71.9
No	7.9	3.1	6.5	3.1
Can't know	26.3	28.1	16.1	25.0
Effect of the 1997 readjustment on own holding				
Held plots lost	23.7	3.1	25.8	3.1
Additional plots gained	18.4	21.9	12.9	18.8
Previous holding remained unaffected	55.3	71.9	54.8	62.5
Had no land before and gained by then	-	3.1	6.5	9.4
Other*	2.6	-	-	6.3

* The category 'other' in the last question includes respondents who, for example, lost some plots at one place and gained equal-sized one at another place.

The proportion of farmers who reported that their participation in the SWC works was not at their own wish is about 55% of the total. Contrasting this figure to the proportion of farmers who are in favour of state ownership of land (84%) with its insecurity implications, it is difficult to conclude that lack of private ownership of land is a major factor holding back farmers from participating in the SWC work. The Chi-square test was performed to see the relationship between participation of respondents in the SWC works and their suggestions on whether land should become absolute private property of the present users. The result indicates absence of a statistically significant association between the two ($\chi^2 = 0.329$, $p = 0.566$). Similarly, chi-square analysis reveals that a statistically significant association does not exist between respondents' participation in the SWC works and their expectation of land redistribution in the future ($\chi^2 = 1.322$, $p = 0.250$). Nevertheless, householders who lost part of their holdings by the 1997 readjustment were found to be less willing to participate in the SWC activities ($\chi^2 = 5.567$, $p = 0.0183$).

It was also learned during focus group discussions with farmers that security of tenure was not the number one discouraging factor from undertaking soil and water conservation activities. In view of the farmers, in fact, periodic land redistribution is a necessary means of wealth (poverty) redistribution among themselves and between generations. The only thing that needs to be taken care of, according to the farmers, is the frequency with which land redistribution should take place and the way it should be implemented. They generally thought that readjustments at intervals of about 15 to 20 years will be justifiable between generations; and fair and judicial implementation of a redistribution with no discrimination of whatsoever would be appropriate for contemporary land users. This may also indirectly indicate that the farmers require security of tenure at least for the period of time mentioned if longer-term plans for improving and protecting the land are to be effected.

The conclusion to be drawn from this section is that, private ownership of land will be an incentive towards sustainable land use. But, it may not be true to think that private ownership alone will be a fair guarantee of circumvention of all the problems of resources degradation. Sutcliffe (1995) has also arrived at a similar conclusion in his study of soil conservation in highland Ethiopia that land tenure security is 'not a sufficient factor' for farmers to invest in SWC works. At the same time, this conclusion is in disagreement with other studies (e.g. Mirgissa, 1994; Yeraswork, 2000) which concluded that Ethiopian farmers lack concern for land conservation because of the insecure tenure.

SWC technologies

In the Chemoga watershed, the SWC technologies under implementation were physical structural measures: *fanya juu* bunds, stone bunds, diversion ditches and check dams. Of these, farmers were more willing to participate in diversion ditches and check dams construction than that of stone bunds and *fanya juu* bunds. On the other hand, *fanya juu* bunds were the dominant structures under construction in cultivated fields, selected by the technical experts of the agricultural office of the Gozamen Woreda for being space saving and swiftly transforming into effective terraces (communication with the DAs). And it was mainly in the construction of this structural measure that the majority of the surveyed farmers professed their participation was not undertaken voluntarily. The previous sections showed that the primary reasons for this were not problems of awareness about land degradation hazards or labour shortage of householders, nor the feeling of insecurity on lands possessed. This section shows that the problem was actually associated with the technology itself. Table 7 shows the reasons given by farmers for discommending *fanya juu* construction in their farms.

Table 7. Farmers' reasons for discommending the *fanya juu*- % of respondents

Reason	Dangule	Keny	Sinan	Yegagna
Takes up too much land	5.3	12.4	6.5	6.2
Does not protect from erosion	18.4	18.8	22.6	24.1
Worsens the problem of erosion	56.3	53.1	67.7	63.6
Breeds pests like rats	2.6	6.4	-	3.1
Other*	17.4	9.4	3.2	3.1

*The category "other" includes per cent of respondents who gave answers different from the enlisted ones.

Of those farmers who responded that they were participating in the SWC works against their interest, the majority reasoned that the *fanya juu* bunds rather heighten the severity of the problem of erosion (60% of the total). According to these respondents, experience with *fanya juu* bunds constructed in the previous years had shown them that the structures definitely cause more erosion damage in their fields. Asked how the structure could cause more damage, the farmers brought up failure of the bunds as the main reason. As the structure collects too much water all along its length, the farmers reported, it spills downslope at its weakest point and then releases the stored energy- the water. Once such happens to a bund, it becomes a cause to the disintegration of several bunds downslope. The cumulative damage by this chain process becomes massive. In each of the study villages, the farmers mentioned several gullies that 'belonged to (or were caused by) the government'. Some 20% of the respondents maintained that the structure is ineffective. Being space taking and providing fertile ground for pests to reproduce were also mentioned as important problems of the *fanya juu* structures.

In addition to the reasons mentioned in Table 7, the farmers in Dangule added that the *fanya juu* structure caused moisture stress to their crops by draining the water off the fields with little time given for infiltration to take place. Even with better infiltration rates that could occur in the absence of the structures, the farmers argued, supplementary irrigation was a requirement to get good harvests. The structure has now rendered impossible the practice of supplementary irrigation as it forms an obstruction to the gravity circulation of water within their fields. This is perceived as a major problem causing yield declines. However, it was learned from field observation that the area does not seem to require any supplementary irrigation during the main growing season. The water that the farmers believed was being used for irrigating crops is probably serving as a buffer against frost damage. Frost was mentioned by the farmers to be a major problem of crop production in Dangule and Sinan villages. This is in itself an interesting indigenous practice which needs to be encouraged and adopted by farmers in other parts of the country where frost occurrence is a problem.

The complaints of the farmers appeared rational. It was observed that construction of the *fanya juu* structures did not consider any real field situations. The DAs simply followed guidelines of manuals prepared in reference to slope inclinations and categorized by agroecologies. Referring to agroecologies in broad terms is an unfavourable generalization and certainly insensitive to microscale biophysical and socioeconomic realities. Also, probably as important as information on the slope angle is data on intensity and amount of rainfall. These aspects of the rainfall are not considered at all by the DAs. Without such basic data to estimate how much runoff will be generated in the fields, it is practically impossible to determine dimensions and spacing of SWC structures. Moreover, construction of the *fanya juu* structures was carried out in level and only moderately sloping lands (≤ 20% slope) for fear it would collapse if built on steeper slopes. Steeper slopes still under cultivation, which farmers would prefer to be treated, are thus left unattended and suffer from severe damage.

The conclusion of this section agrees with conclusions arrived at by Belay (1992) in his study in southern Ethiopia. That is, farmers are willing to conserve their soils and lands but demand for more appropriate technologies; and the major cause of erosion in areas treated with *fanya juu* is poor construction of the bunds. Other studies carried out elsewhere have also concluded that farmers fail to adopt or adapt SWC technologies not for lack of concern to sustainable land use but for inappropriateness of the technologies provided. For instance, Kerr and Sanghi (1992) reported that in India's semi-arid tropics, farmers failed to maintain or even intentionally ruined the introduced SWC measures because the measures were not suitable to their small farms. According to Reij (1991), farmers were at times right in rejecting introduced SWC technologies because it caused greater damages than would happen without the measures.

Conclusions

The results of this study indicate that the majority of the farmers considered SWC activities that were underway in their communities to be mandatory development works in which the village administration and the DAs forced them to participate. This suggests that the practice did not respect participatory principles, and was thus a conventional top-down type. The most important factor discouraging the farmers from willingly participating was found to be associated with the effectiveness of the SWC techniques under construction. Awareness about soil erosion as a problem, labour shortage, and land tenure insecurity were found to be less important as an explanation for the disinterest shown by most of the farmers towards the conservation works.

Therefore, the important factors that need immediate consideration for SWC endeavours in the study watershed or the Region at large are: (i) SWC structures have to be carefully designed and constructed taking into account ground realities, and (ii) participation of the farmers has to come from their conviction engendered by the demonstrated effectiveness and efficiency of the technologies. Alternative SWC technologies will have to be considered in this regard, and we believe that the farmers should be involved fully in the planning and design of the measures. It is essential to think about conservation technologies which will be accepted by farmers because experience within the country has shown that conservation work without farmers' acceptance leads nowhere. Farmers' endorsement will be obtained if they are genuinely involved in all stages of problem identification, alternative solutions prescription, implementation and evaluation of effectiveness and efficiency of the solutions. In other words, participation of the farmers should be a partnership leading towards a common goal. Involvement as labourers is different from participation as development partners (Chambers, *et al*., 1993). Farmers are often said to participate while in fact they are participating in implementation of projects engineered for them by subject-matter experts elsewhere. This is exactly what is happening in the study watershed. Such a practice can never take the name participation and should never be expected to be sustainable. Mistaking mobilization for participation entails failure that erodes farmer's confidence in government activities (Gedion, 2001). Real participation in resources conservation is, in fact, a question of empowering the farmers to decide on their own and their children's livelihood potentiality. Therefore, a guiding principle for a truly participatory approach to SWC in the Ethiopian highlands can be found in Smith et al. (1994:1099):

Tell me and I will forget
Show me and I may remember
Involve me and I will understand
Empower me and I will act.

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Chapter 9

Towards integrated watershed management for resource conservation in the Chemoga watershed, northwestern highlands of Ethiopia

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Towards integrated watershed management for resource conservation in the Chemoga watershed, northwestern highlands of Ethiopia

Abstract

Resource degradation is a critical economic problem in highland Ethiopia. Past efforts at conservation did not bring about significant results. Hence, there is an urgent need to tackle the problem through new conservation strategies, approaches and technologies. Multiperspective and multiscale studies were conducted in the Chemoga watershed, representative of the northwestern highlands of the country, for a detailed understanding of the processes, extent and rate of resource degradation. The results revealed that there are interlinked problems of expansion of croplands at the expense of natural vegetative covers, a high rate of soil loss due to water erosion, adverse changes in some soil properties and depletion of the water resource. The physical interdependence between upstream and downstream land uses was evident both at the watershed and subwatershed scales. These facts suggested that integrated watershed management approach is the appropriate option for resource conservation in the area. This paper describes the possibilities by which integrated watershed management approach will be put into practice. It is discussed that effective and sustainable implementation of the suggested approach will require: microwatershed-level planning and pursuing of farmer participatory processes, building upon indigenous knowledge systems and addressing of farmers priorities, ensuring of land tenure security, implementation of targeted and effective incentive systems and providing of client-oriented extension service.

Key words: resource degradation, watershed management, participation, policy, Ethiopia

Introduction

Resource degradation constitutes an environmental, economic and social problem in highland Ethiopia. It has contributed to the persistent food-insecurity and poverty of the rural people (Hurni, 1993; Sutcliffe, 1993; Girma, 2001; Sonneveld and Keyzer, 2003). The problem has been recognized since the early 1970s and considerable efforts have been made since then to rehabilitate degraded environments and stop further degradation from occurring (Wood, 1990; Girma, 2001). Nevertheless, the achievements so far are minimal (Azene, 1997; Yeraswork, 2000). Resource degradation thus remains perilous to the national economy. It needs to be tackled through new conservation strategies, approaches and technologies. The immediate cause for the degradation of resources is the unsustainable exploitation the farmers' practise forced by their legitimate need for survival. The increasing farming population, in the absence of alternatives, has caused extensive destruction of forests, expansion of cultivation into steeplands, increase of total livestock numbers and accelerated soil degradation (Hurni, 1993; Girma, 2001). The situation in the Chemoga watershed provides a typical example of the processes of resource degradation occurring in many parts of the Ethiopian highlands.

The Chemoga watershed lies within $10^0$18'N to $10^0$39'N and $37^0$44'E to $37^0$53'E. In administrative terms, it is located in Gozamen woreda (district), East Gojjam Zone, Amhara Regional State. The climatic condition is generally humid. The mean annual temperature is 14.5^0C and the average annual total rainfall is 1300 mm. More than 75% of the total rain falls in the four months of June to September (*kiremt* season). The dry months are October to February (*bega* season), when less than 5% of the annual total rainfall occurs. The total area of the watershed is 364 km^2, and the total population is around 40,768, according to the rural population density (112 persons/km^2) estimation for the Gozamen woreda (Gozamen Woreda Office of Agriculture, 2001). This population density is slightly higher than the average for the Amhara Regional State (99.6 persons/km^2) and much higher than the national average (49.3 persons/km^2) (NOP, 1999). The farming system is a typical mixed crop-livestock system that is carried on a subsistence scale. Incomes from off-farm employment are very scanty (Woldeamlak, 2001). Land and livestock are therefore the fundamental bases of livelihood to the people, with which they lead a sedentary life. Presently, land degradation constitutes a hazard to the livelihood of the population as shown by various empirical studies carried out in the area.

During the past four decades, land use/cover changes have occurred in the Chemoga watershed. But agricultural use has remained the main type. The major change was also the expansion of cultivated lands at the expense of open grazing lands (Woldeamlak, 2002). Expectedly, the expansion of cultivation has been into steepland areas that were previously used for livestock grazing for being only marginally suitable for crop cultivation (Fig. 1). The major land use type being agriculture and this having extended into steeplands over time has implications on runoff generation, soil erosion and sedimentation problems. For instance, there is extensive flooding and sedimentation problem in the area of marshlands in the downstream reach of the watershed, which has become a major problem to the local farmers by putting out of use temporarily a large tract of land that is used for livestock grazing (Woldeamlak, 2002). The land use system has also led to deterioration in some physical and chemical properties of the soils (Woldeamlak and Stroosnijder, 2003). By analysing soil samples collected from the major land cover/use types in the area (natural forests, cultivated lands, grazing lands and eucalypt plantations), Woldeamlak and Stroosnijder (2003) concluded that the land use system and its trend of change, which has been the increase of areas under cultivation and eucalypts, have not been beneficial to the soil resource.

Figure 1. Expansion of cultivation into marginal areas and upland degradation in the Chemoga watershed, Ethiopia.

Unfavourable changes were also detected in the stream flow of the watershed, which is the only source of water to the local people for domestic consumption as well as for their livestock. Between 1960 and 1999 the total annual stream flow decreased at a rate of 1.7 $mmyr^{-1}$ whereas the annual rainfall decreased only at a rate of 0.29 $mmyr^{-1}$ (Woldeamlak and Sterk, forthcoming). The decrease in the stream flow was more pronounced during the dry season (October to May). The observed adverse changes in the stream flow have apparently resulted from the changes in land cover/use and/or watershed degradation. Soil erosion by water from cultivated lands is another problem in the area. Assuming that interrill erosion contributes 30%, soil loss rates were estimated at 18 $Mgha^{-1}$ in the upstream and 79 $Mgha^{-1}$ in the downstream parts of the watershed, which by all measures exceeds the rate of soil formation in the area (Woldeamlak and Sterk, In press). The same study also reported the presence of a strong physical interdependence between fields located in upstream and downstream positions in terms of soil erosion and sedimentation processes, suggesting that conservation in one farm will do little if the other farms in a higher position are not conserved. The existing effort at resource conservation, which is focused on SWC in cultivated fields and is being undertaken as part of the extension package of the government, is not oriented towards bringing about meaningful results (Woldeamlak and Sterk, 2002).

The farm households in the Chemoga watershed are, therefore, facing interlinked problems of resource degradation. The people are poor and live on average annual incomes ranging from Birr 779 (1.00 Birr ~ 0.125 $US) in an upstream village (Dangule) to Birr 1692 in a downstream village (Yegagna) per household, which has an average of 6.3 members (Woldeamlak and Stroosnijder, forthcoming). The degradation of the resource base will exacerbate the poverty under which they are currently living. Hence, there is an urgent need for resource conservation even to the maintenance of the subsistence living of the people. Given the interrelation of the resources, interaction of the degradation problems and the apparent upstream-downstream interaction, integrated watershed management (IWM) approach is the appropriate and justified option. The aim of this paper is to describe the possibilities of implementing IWM in the Chemoga watershed. The arguments presented are based on findings of the various empirical studies carried out in the area and review of pertinent literature.

Watersheds as planning frameworks for resource management: the concept of IWM

Watershed is a geographic area that sheds-off water to a common outlet. Topographic divides separate a watershed from another watershed/s. The term is used independent of size; a watershed can be as small as a few hectares or as big as several thousands of km^2. In the case of the latter, the term basin is often used. The common and central characteristic of all watersheds is that ‘they hold multiple, interconnected natural resources: soil, water and vegetation; and impact on one resource invariably affecting the status of the others’ (White, 1992:1). Water is the integrative element of a watershed as it flows downhill, irrespective of social and political boundaries, and creating an organic linkage between upstream and downstream areas. With the downslope flow of water, upstream resource use practices can incite a chain of impacts to which downstream areas are naturally laid open. For instance, soil erosion in upstream areas will not only cause degradation of agricultural lands on the site, but also create problems of water pollution, reservoir siltation, channel sedimentation and increased flood flows in downstream areas. The watershed context is, therefore, a ‘unifying framework’ for an effective and integrated investigation and understanding into the complex and reciprocal linkage between watershed resources- soil, water and vegetation- and the interaction between upstream and downstream land uses (Gregersen et al., 1996; Sheng, 1998; Ravnborg and Guerrero, 1999).

Because of this ‘unifying’ significance, watersheds are presently widely acknowledged to be the logical natural units for the integrated and sustainable management of natural resources; and the practice is popularly known as IWM. By the principles of IWM, all types of land uses in a watershed- cultivated lands, grazing lands, forestlands and others- are to be holistically viewed and a mix of different types of management measures are to be employed to get coactive effects. The IWM approach is distinguished in the Agenda 21 of the UNCED as an effective means of achieving concurrently economic development and conservation of natural resources (UNCED, 1992). The same was also underscored in the Brundtland Report- Our Common Future- of the World Commission on Environment and Development (WCED) (WCED, 1987), and reinforced in the objectives of the UNCCD (UNCCD, 1994).

There is debate on the relative importance of on-site versus off-site significance of the IWM approach to resource management. Generally, it used to be considered as particularly appropriate in cases where the off-site benefits (costs) of conservation (degradation) are rather important (De Graaff, 1996). However, in the case of developing countries such as Ethiopia where smallholder agriculture is the dominant form of resource use in upland areas and few developments are found in downstream areas, the IWM approach to resource conservation is essential primarily for its on-site benefits, as the watershed is the naturally appropriate unit to deal with the naturally inseparable natural resources. In such environments, according to Kerr et al. (1999), resource conservation actually has greater on-site benefits than off-site benefits, with only largely localized externalities within a scale of microwatersheds. This suggests that small watersheds (or microwatersheds) are the appropriate planning units when the IWM approach to resource conservation is to be pursued for the sake of its on-site benefits. The appropriate microwatershed size in the highland Ethiopian setting will be in the range of 100 to 300 ha which is accommodating approximately 100 to 200 households.

At the spatial scale of microwatersheds, the interrelatedness of natural resources and the interdependence of people in their use of these resources are very apparent. The interrelation of the resources stands to rationalize the need to pursue an integrated approach for an effective conservation planning. And, the visibility of the interdependence of people in their resource-use practices constitutes a cohesive force to bind them together in the watershed context for a community-based resource management, without which, according to Murphree (1993), ‘there is little reason to be optimistic about a sustainable resource conservation’. Implementation of the IWM approach to resource conservation even at the microwatershed scale can involve, as is generally the case with watersheds of larger sizes, a formidable challenge of bringing together the physical boundaries of watersheds and the social and political boundaries of communities (Rhoades, 1998; Johnson et al., 2001; Knox et al., 2001). There are no standard guidelines by which this problem can be overcome. The best available option is to maintain flexibility and work ‘within social boundaries applying the watershed approach’ (Johnson et al., 2001; Knox et al., 2001). Experience has shown that following physical boundaries strictly and neglect of the social boundaries generally lead to failure of watershed management initiatives (Knox et al., 2001). The possibility of devising a compromised boundary by taking into account both the biophysical and social boundaries is elaborated below in the context of the Chemoga watershed. When the biophysical framework of watersheds and the social boundaries are brought to form a fitting overlay and the local people are involved in the resource management undertakings, watersheds as planning units become 'physically defined subsets of rural society' (White, 1992:12) and not just hydrological entities.

Involvement of the local people is the core of microwatershed-based resource conservation (Sharma et al., 1997; Sharma, 1999). In view of this, Sharma et al. (1997) define IWM as: '*utilisation and conservation of land, water and vegetation resources at farm household and micro-watershed level for continuously improved livelihood and human development*'. The ultimate objective is thus development at the local-level through appropriate use and management of natural resources by the main stakeholders- the local people. It is about local people taking a coordinated local-level action for proper management of resources to control their own destiny in the development process. In other words, the IWM approach acknowledges that individual farmers (or communities as a group) are the best managers of resources because they realize that their dependence on resources for livelihood is nearly absolute. Moreover, conservation and development of natural resources- vegetation, soil and water- are not new to rural communities but as old as and the background for their existence (Sharma, 1999). What is advocated for is, then, to build on these venerable experiences of society through facilitatory interventions using microwatersheds as planning frameworks and transform communities into resource management institutions (Murphree, 1993).

Concisely put, the reasons for preference of the microwatershed context to resource conservation are the following guiding premises:

i. Watershed resources- vegetation, soil and water are highly interactive. That is, the problems of devegetation, soil degradation and water resource depletion are interrelated. This implies that vegetation, soil and water cannot be managed for sustained availability in isolation from each other. Any effort at, say, managing the natural vegetation cover is futile unless the expansion of cultivation into areas with natural vegetation is stopped. This requires sustained or even improved productivity of the cultivated fields, for instance through adequate SWC. Hence, viewing the whole of a watershed as a system and treating simultaneously all forms of land uses in the unit is essential.

ii. Soil erosion and sedimentation processes, which are due to the downslope flow of water, affect many land users in a watershed, though to varying degrees. This scenario of 'transboundary' interdependence is evident to the farmers, particularly at the micro-scale, and proves the need to take the whole of the watershed as a unit for SWC purposes. If individual farm approach is to be used, for instance, runoff from untreated farms will cause damage on the treated ones positioned downstream. Moreover, watersheds often consist of land under communal use (e.g. grazing lands, riverine trees) that require communal management. For these reasons, farmers may easily perceive resource management as requiring cooperative, coordinated and group action; and thereby a matter of social relations.

On implementing IWM in the Chemoga watershed- technical issues

i. Microwatershed-level planning and farmer participation

In the context of the Chemoga watershed, and in highland Ethiopia in general, implementation of IWM approach for resource conservation needs to be small-watershed-based. An appropriate size of a planning microwatershed will be in the range of 100 to 300 ha, depending on site-specific conditions. This is mainly from the point of view of factors affecting participation of the farmers in the 'bottom-up' planning and implementation processes, which is the key to success. The need for involvement of the farmers in resource conservation efforts is too obvious from experience within Ethiopia (Woldeamlak and Sterk, 2002) and elsewhere. As a matter of fact, as Versfeld (1995:147) has succinctly put, '…development is dependent on people and that people are a fund of knowledge, ideas and implementation capacity'. Evidently, committed participation of the farmers can have both short-term benefit of effective implementation and long-term benefit of sustainability.

At the scale of microwatersheds, enabling conditions exist for participation of the farmers; their number is small, the physical interdependence (upstream-downstream interaction) among the farmers is more apparent, and obstructions to collective action such as infrequent contacts due to physical distances are at minimum. At the scale of microwatersheds and fewer farmers involved, collective action will be facilitated because of mutual trust, shared values and indigenous knowledge, reciprocated action and the effective traditional sanctioning mechanisms. Furthermore, the smaller the planning watersheds the farmers involved will be not only few in number but also more homogenous in terms of production objectives, opportunities and resource constraints, under which 'collective action will be most easily achieved' (Swallow et al., 2001).

For implementing the IWM approach for resource conservation in the Chemoga watershed, the first step is, therefore, the identification and delineation of microwatersheds which are to be used as the conservation planning units. This should be done by technical experts (extension workers) with the active involvement of the farmers. The village boundaries should be the first consideration. The boundaries between the villages, which are either ridges (water divides) or the channels of streams, generally also mark boundaries of property rights in the area. Then, each village can be subdivided into 'conservation units' following how surface water flows (applying the watershed approach). Figure 2 illustrates this schematically. As shown in the Figure, the Chemoga watershed can be divided into its constituent villages (V_1 to V_n). Each village can in turn be subdivided into the smaller 'conservation units' (CU_1 to CU_n), which are the hydrological entities. In this scheme, the 'conservation units' will be systematically fitting within the social boundaries of the village administration; thus avoiding the need to create cross-community watershed management institutions. The 'conservation units' defined in this manner will also be easily understood by the local farmers, who already have the tradition of cooperation for the safe disposal of surface runoff by constructing diversion ditches and waterways (locally known as *feses*) by observing how surface runoff flows (among those cultivating fields in upstream and downstream positions).

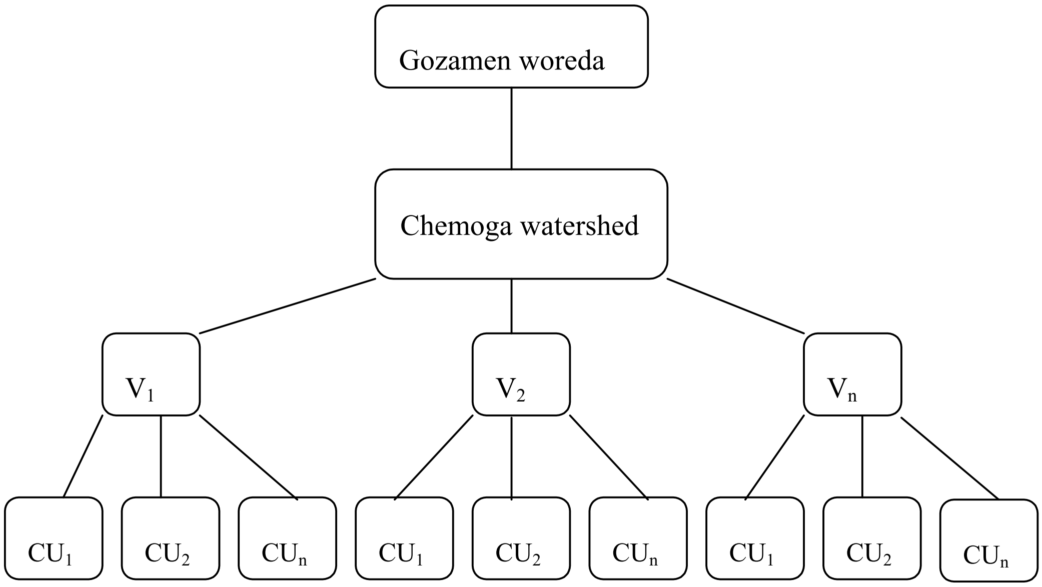

Figure 2. Schematic organization of the Chemoga watershed into ‘conservation units’ (V= village; CU= conservation unit).

Once the planning microwatersheds are delineated, the farmers (the resource users) can together form watershed management groups to be presided by democratically elected committee members. The process of formation of the watershed management groups and election of their representatives (leaders) will require effective facilitation by extension workers. Experience elsewhere has shown that proper representation of all the stakeholders in a microwatershed is vital to achieve success (Ravnborg and Guerrero, 1999; Ravnborg and Westermann, 2002). Generally, influential elders (*yager shimagile*) and clergymen can play important roles. The influence of these members of the communities in resource conservation was noted in a study in the Chemoga watershed by Woldeamlak (2002), and in north Shewa by Azene (1997). Under the leadership of the committee members and with technical assistance from extension workers, the watershed management groups will plan and execute land management activities collectively and by turns rotating from one field to another until all the land in the planning microwatershed (both under private and communal use) is treated. The land management plans will be prepared for the entire microwatershed, but may need adaptations to farm-level realities. Azene (1997) has shown practically how land management plans can be prepared at the microwatershed scale and adapted to farm-level situations.

Conservation committees will also be established at the village level having representatives from committee members of each ‘conservation unit’. The main concern of the village level committee will be the sustainable management of common property resources at the village level such as forestlands, grazing lands, woodlands, floodplains and riverine trees, which will lie outside of the ‘conservation units’ and are traditionally used by all residents in a village. Federating the village level committees into the level of the whole of the Chemoga watershed will then become the responsibility of a concerned government authority at the district (Gozamen woreda) level. Upscaling to the level of the whole of the watershed is necessary because the ultimate objective of the microwatershed approach is to achieve sustainable management of the entire area of the watershed 'from the bottom up' through an incremental process over space and time.

In the Chemoga watershed, the tradition of working together in reciprocal labour exchange groups during plowing, harvesting and threshing already exists (e.g. *debbo*, *wenfel*), as is generally the case in many parts of highland Ethiopia (Azene, 1997; Tesfaye, 2003). The communities also have established norms of conflict resolution through the influential roles of the elders (*yager shimagle*) and clergymen (Fig. 3). Hence, the establishment of the 'conservation units' and the watershed management groups and implementation of the IWM approach to resource conservation will be a matter of building upon the existing tradition. Besides improving on the existing tradition of collective action for effective resource conservation, the formation of such farmer groups (organizations) will also enhance the farmers' empowerment to make decisions on resources use and management for their improved livelihood. There are a number of IWM projects elsewhere in the world appraised as having improved the livelihood of the farmers and the successes attributed to the participatory processes pursued that empowered the farmers (see Sharma, 1997; Hinchcliff et al., 1999).

Figure 3. An indigenous conflict resolution occasion (conflict over field boundary) in the Chemoga watershed, Ethiopia.

ii. Building on indigenous knowledge systems and addressing farmer priorities

The farmers in the Chemoga watershed, as is the case in many parts of highland Ethiopia, have a pool of indigenous knowledge with which they use and manage their land resource. They make efforts to conserve their soils against erosion by applying a range of conservation techniques such as the traditional waterways (*feses*) and diversion ditches; and they try to manage fertility of their soils through such techniques as crop rotation, manuring, fallowing and leaving trees amid cultivated fields (traditional agroforestry). The farmers plant trees for economic reasons and in some cases, as in the Dangule village (in the upstream part of Chemoga), they make efforts to preserve indigenous forests for their ecological benefits (Woldeamlak, 2002, In press). These indigenous practices and traditions ought to be at the base of new and improved resource management practices that would be introduced, to ensure social acceptability and sustainability.

Resource management initiatives and technologies that are foreign and alien to the farmers are unlikely to be accepted and adopted. For instance, the SWC technologies that were recently under implementation in the Chemoga watershed were physical structural measures: *fanya juu* bunds, stone bunds, diversion ditches and check dams (Woldeamlak and Sterk, 2002). Of these, the farmers were more willing to participate in diversion ditches and check dams construction than those of stone bunds and *fanya juu* bunds. On the other hand, the *fanya juu* bunds were the dominant structures under construction in cultivated fields, selected by the technical experts of the local office of the agriculture ministry for being space saving and swiftly transforming into effective terraces. And it was mainly in the construction of this structural measure that the majority of the surveyed farmers (n = 133) admitted their participation was not undertaken voluntarily (Woldeamlak and Sterk, 2002). The major reason given was its perceived ineffectiveness. This negative evaluation of the introduced technology was partly because of the fact that it was far from their traditional SWC practices. Moreover, construction of the structure was carried out in level and only moderately sloping lands (< 20% slope) for fear it would collapse if built on steeper slopes. Steeper slopes still under cultivation, which the farmers preferred to be treated, were rather left unattended and suffered from severe damage.

Thus, the SWC undertakings were not related to the existing indigenous practices, nor were they addressing the farmers' priorities and preferences. The result was that the farmers preferred their traditional practices to the introduced *fanya juu* bunds. Their enforced participation in construction of the latter simply means the likelihood of it being demolished as the coercive force withdraws is very high. Therefore, indigenous resource management practices, which are acknowledged by the farmers themselves as effective and important, ought to be the basis for introducing new ones to ascertain success and sustainability. The ideal of IWM also opts for more 'people-friendly and process-based' activities which will be smoothly fitting into the farmers' styles of living (Johnson et al., 2001).

As stated above, the farmers were more willing to participate in the construction of diversion ditches and check dams than the *fanya juu* bunds. This was partly because effects of the diversion ditches and check dams were discernible to them, while that of the *fanya juu* bunds, which were being established within cultivated fields mainly to control sheet and rill erosion, were not obvious enough, particularly compared to the space the structures take up. It was also learned from another study that the farmers were interested in planting trees because of the direct benefits it yields (Woldeamlak, In press). This means that in order for farmers to accept and adopt conservation technologies and willingly participate in conservation activities, the technologies to be implemented should have perceivable benefits. Hence, for an effective implementation of microwatershed- and people-based resource conservation, the farmers would need to be convinced of the benefits of improved conservation technologies through various means such as visits to other areas with successful implementation, using demonstration sites or an ex-ante cost-benefit analysis. A good example of an ex-ante cost-benefit analysis tool is being developed and tested in the east African countries of Kenya and Tanzania (Sterk and Van den Bosch, 1999). In general, it is much preferable for the net benefits of conservation to be materializing within a short period of time, say a year or two. Without quick and direct benefits, farmers would see no reason to get involved in IWM activities. Quick and perceivable benefits, thus, constitute the link between farmers' willingness to participate in and long-term economic, social and environmental benefits of IWM. Dealing with income generating resource management activities also means addressing of subsistence farmers' needs and priorities- that of food security and poverty alleviation (Scherr, 2000).

On implementing IWM in the Chemoga watershed- policy issues

i. Securing land tenure

In Ethiopia, land has been under state control since the 1975 land reform proclamation of the socialist *derg*. In view of many researchers, this property ownership regime has been a source of insecurity for farmers to invest on lands they cultivate for long-term benefits (Azene, 1997; Yigremew, 1997, 1999; Yeraswork, 2000). A study conducted in the Chemoga watershed also revealed that one of the reasons given by the farmers for not having planted trees privately was the insecurity over lands operated (Woldeamlak, In press). According to these empirical evidences, the existing land tenure system with its insecurity implications will remain a constraint to sustainable resource use and increased food production in the country. Therefore, securing land tenure will be a vital policy measure for effective and sustainable implementation of IWM. Guaranteeing land tenure security will not only be an incentive for the farmers to adopt land-conserving practices, but it will also be a means of empowering them to be determinants of their own course in the development process.

Securing land tenure should not necessarily mean privatising land. It would be sufficient to guarantee use right of the farmers over a sufficiently long period of time to allow recovery of investments in resource management works, which normally takes long cost-recovery periods. According to Woldeamlak and Sterk (2002), the state ownership of the land was not the single most important factor discouraging farmers from willingly participating in the construction of newly introduced SWC technologies in the Chemoga watershed. Out of 133 households covered by their survey, some 84% were rather in favour of the state ownership of the land with its insecurity implications. In view of some of the farmers, indeed, periodic land redistribution, as they said at intervals of 15 to 20 years, was a necessary means of wealth (poverty) redistribution among themselves and between generations. This suggests that secure use rights over an extended period of time would be a good incentive for the farmers to adopt conservation technologies at the farm level.

In addition, a policy framework needs to be devised by which lands that are currently under communal use (not under operation by individual farmers) will be titled to the local people for a communal but economically and ecologically sound use. Presently, there is a considerable area in the Chemoga watershed, mainly on steep slopes that are unsuitable for cultivation, that is under communal use as grazing land and a significant part of it is highly degraded, barely covered with vegetation and more of a wasteland type. A good part of these lands can be used for livestock grazing, but require effective pasture and grazing management systems for sustainable use. And, the remaining can be used for community forestry development, providing wood for fuel, construction and farm implements to the local people and contributing positively towards watershed ecosystem health.

ii. Use of targeted and effective incentive systems

In Ethiopia, the food-for-work approach, using grain and edible oil, was used extensively as a direct incentive to mobilise labour in the SWC efforts of the 1970s and 1980s. According to some researchers, this approach had a greater negative (unintended) effect than a positive one: it became a disincentive for initiatives of SWC to be taken by the farmers themselves (Wood, 1990; Azene, 1997). According to Azene (1997), the food-for-work approach had made the farmers develop total dependence on the grain and oil handouts not only to participate in the SWC activities, but also for the maintenance of the physical structures constructed in their privately operated fields by the campaign works. Similar experience, where the provision of economic incentives and subsidies rather undermined sustainability of watershed management interventions, abounds in many countries of south and southeast Asia (Thapa, 2001). Given these experiences within the country and elsewhere and the fact that the government has too insufficient economic capability to support resource management activities throughout the vast territory of the country, incentives will be hard to justify in the existing Ethiopian situation.

Nevertheless, there are circumstances under which implementation of targeted incentives can be retained valid policy options. These include cases where: (i) rehabilitation of degraded lands has much greater social benefits than private, and (ii) the farmers are to undertake conservation works that are not traditionally part of their day-to-day farming activities and the benefits of these works are to be realized far into the future or downstream (e.g. prevention of silting up of reservoirs). In these cases, the government, on behalf of society at large and future generations, ought to employ some incentives to compensate the farmers for the time, labour and capital investments they will make. In the Chemoga watershed, soil erosion from cultivated fields is a serious threat to food production; and this is acknowledged by the farmers themselves (Woldeamlak and Sterk, 2002, In press). Given this, the farmers will have sufficient private returns for implementing SWC measures without any sort of incentives, so long as they can be provided with a 'basket of appropriate technologies from which to choose'. Though not sufficient, as other preventive constraints may exist, profitability of SWC measures from the farmers' perspective is a necessary condition for their adoption. Incentives will have little additional effects in this regard.

There are areas, however, particularly in the upstream part of the watershed that will have greater social and inter-generational benefits should they be conserved and well-managed. These lands include very steep slopes that require being forest-covered and render enhanced ecological services to the society at large. Supporting afforestation of such lands therefore becomes essential from the government's perspective, which is charged with the responsibility of being a guardian for the benefits of society as a whole and the generations to come. As the local farmers will have imperceptible returns from involving in the afforestation of these areas, the use of incentives will be required and it will be an appropriate policy option. By the time of fieldwork for the studies cited in this paper, for instance, there was some area under indigenous forest cover in the upstream part of the watershed (in Dangule village) which had been preserved and protected by the local people by their own initiative, believing that the protection of the forest would sustain the flow of springs there in. The forest area was protected from any kind of destructive use by a guard, whom the people themselves employed through a contributed wage. This protected area is found at the very source of the Chemoga stream; the source of water to thousands of people and livestock in the downstream areas. The benefits of this initiative are therefore not exclusive to the local people. Hence, it is appropriate for the government to take over the cost of paying for the guard, which will be an incentive to the community to adopt more conservation-based use of the forest resource, through its local office of the agriculture ministry or that of the environmental protection authority.

Besides, incentives will be appropriate as cost-sharing arrangements between upstream and downstream beneficiaries of IWM undertakings. Even though off-site effects of upland degradation are not very large in the Chemoga watershed, as there are no reservoirs and dams, there are many downstream benefits that will be generated by IWM activities that will justify a policy of cost-sharing (e.g. enhanced dry-season stream flow, improved water quality). Therefore, implementation of targeted and effective incentive systems will be a commendable policy option for resource conservation through an IWM approach in the Chemoga watershed. The relevance of the incentives approach in promoting adoption of SWC measures in Ethiopia has also been underscored by Shiferaw and Holden (2000). They suggested the use of such incentives as food-for-work, credit or fertilizers as inter-linkage mechanisms. As suggested by Azene (1997), grain and oil handouts may be used as food-for-work incentives. But, care ought to be taken not to end up creating a dependency mentality among the farmers and hamper their own initiatives for resource conservation and development. In our point of view, the farmers should rather be provided with alternative types of incentives from which to choose such as establishment of schools, health posts, flour mills, instead of just grains for food-for-work.

iii. Providing client-oriented extension service

In Ethiopia, the extension approach currently being pursued is Participatory Demonstration and Training Extension System (PADETES). This approach has been adopted from the SG-2000 approach which came into being in Ethiopia in 1993 (Tesfaye, 1999). The PADETES is simply applying the classical top-down extension approach, commonly known as the transfer of technology (TOT) model. Its major activity is transfer of technologies that are developed in experimental and research sites, which are few in number and certainly inadequate to represent the range of ecological and socioeconomic diversities available in the country. This means, the program lacks flexibility and adaptive characteristic to match local biophysical and socioeconomic settings; and more importantly excludes the direct stakeholders- the farmers- from being involved in the process of technology generation (Tesfaye, 1999, 2003). The farmers are thus relegated to the receiving end.

In addition to the fact that it fails to be farmer-centred, the existing extension system also suffers from a very large farmer to extension worker, officially called development agent (DA), ratio. In the Chemoga watershed, one DA serves 1121 households in Dangule village, 868 in Sinan, 909 in Keny and 772 in Yegagna. Given the rugged landscape and inaccessible situation, a DA serving such a large number of farmers is a formidable challenge. Added to their low incentives (salaries), this seems to have created absence of motivation and devotion and feelings of desperation on the part of the DAs (Pers. com. with DAs). On the part of the farmers, the DAs are seen as belonging to the government bureaucracy because of their involvement with the village administrations in collection of land use fees, fertiliser use payments, reimbursements of credits the farmers take from the local office the agriculture ministry, land redistributions, enforcing the farmers to construct 'unwanted' SWC structures and fining the farmers when they dismantle these structures. The DAs are, therefore, presently not considered by the farmers as honest assistants in their production and conservation efforts.

For an effective and sustainable implementation of an IWM approach for resource conservation and development, the farmers would need to be provided with a new client-oriented extension service, and not a message-oriented one, as is presently the case. A client-oriented extension service will require a fundamental change not only in the existing roles of the DAs as messengers, but also in the roles of the researchers at the Ethiopian Agricultural Research Organisation (EARO) as knowledge and technology creators and the farmers as passive recipients. By the client-oriented approach, the three actors should be working together in a truly participatory process: the researchers working with the farmers to search for solutions to problems of common concern and the DAs facilitating the implementation of proposed solutions to the problems being tackled. This approach will require the researchers and the DAs to be innovative and communicative and with perseverance and dedication to serve best interests of the farmers. In addition, by a new extension approach the farmer to DA ratio should be manageable, payments to the DAs should be commensurate with workloads, and the responsibility of the DAs should be bound to only development activities.

Conclusions

Resource degradation is a critical problem in highland Ethiopia. Previous efforts at conservation did not bring about satisfactory results. The problem thus remains a critical constraint to food security and economic development. Empirical studies conducted in the Chemoga watershed revealed that there are interlinked problems of resource degradation that included expansion of cultivated areas at the expense of natural vegetative covers, a high rate of soil loss due to water erosion, adverse changes in some soil properties and depletion of the water resource. A strong physical interdependence was also observed between upstream and downstream land uses. These facts suggest that IWM approach is the appropriate option for resource conservation in the area.

The IWM approach enables an holistic view of the resources and use of different combinations of measures to address the problems of devegetation, soil degradation and depletion of the water resource in an integrated manner. It also allows consideration of upstream-downstream interaction in designing resource management interventions with a view to making arrangements for cost sharing. Effective and sustainable implementation of the IWM approach will require: microwatershed-level planning and pursuing of farmer participatory processes, building upon indigenous knowledge systems and addressing of farmers priorities, ensuring of land tenure security, implementation of targeted and effective incentive systems and providing of client-oriented extension service. Even though the empirical research findings are revealing the reality in the Chemoga watershed, the facts, analysis and conclusions generally unveil the conditions in much of highland Ethiopia, suggesting that the IWM approach will be an appropriate avenue for a sustainable conservation and development of resources in these areas.

Lasing solutions to the problem of resource degradation should, however, include a number of practical measures. A major one is easing the population pressure on land by putting into effect the national population policy which was crafted in 1993. One of the solutions to the diminution of landholdings suggested by the farmers was in fact reducing population numbers (Woldeamlak and Stroosnijder, forthcoming). This farmer awareness of the problem of ‘population explosion’ is an opportunity for intervention for the implementation of the national population policy. The pressure from the livestock population of the country is also a major contributor to resource degradation in highland Ethiopia (Kebrom, 1999; Girma, 2001). Thus, there is a need to reduce the livestock pressure on land by introducing improved livestock husbandry and pasture management practices (e.g., introducing improved breeds and reducing unproductive livestock, promoting controlled grazing and stall feeding and introducing improved feed production system).

Developing the other sectors of the economy and creating non-farm employment opportunities for the population, in addition to efforts to bring about growth in the agricultural sector, helps to ease the population pressure on land and to alleviate the abysmal rural poverty in the country. Rural poverty alleviation will require appropriate policies to provide the farmers with support services like credit and marketing facilities, alternative sources of energy, education and health services and construction of rural roads, which will, in turn, contribute positively towards resource conservation. As noted by Alemneh (1990), resource conservation in Ethiopia has historically been beset by lack of appropriate rural development policies that encourage sustainable use. Without appropriate policies to alleviate rural poverty, sustainable management of natural resources will remain practically very difficult. In line with this, any IWM effort should aim at attaining both biophysical and social objectives of protection of the resource base and improvement of social well-being of the population. The overall goal should be towards improved food security and alleviation of rural poverty through conservation-based use of the resources as resource degradation is recognised to be a 'cause, symptom and result of poverty' (Blaikie, 1985).

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Chapter 10

Summary and conclusions

Summary and conclusions

Resource degradation is a critical economic problem in Ethiopia. The highlands are the most affected because of the heavy pressure from the human and livestock populations. Past efforts at conservation did not bring about significant results. Hence, there is an urgent need to tackle the problem through new conservation strategies, approaches and technologies. Recently evidences are emerging from experiences in many countries of the world that integrated watershed management (IWM) generally leads to effective resource conservation and improved rural livelihoods. The aim of this thesis was to explore the need for and possibilities of implementing the IWM approach in highland Ethiopia. The Chemoga watershed, a typical watershed in the northwestern highlands of the country, was used as the case study site. Multiperspective and multiscale investigations were conducted on the extent, rate and processes of resource degradation and the existing resource-use and management practices in the area. The major findings from these studies are briefly presented here.

In the Chemoga watershed, land use/ cover changes have occurred during the past four decades. But agricultural land use has remained the main type. The major change that has occurred is an increase of the cultivated area at the expense of open grazing area. Unexpectedly, the forest cover has shown a slight increase. The major land use type being agriculture and this having increased over time has implications on runoff generation, soil erosion, flooding and sedimentation problems. The slight increase in forest cover does not imply a favourable change towards sustainable land use because most of the newly forested areas are eucalypts for wood production, which are known to have a number of negative ecological effects along with its economic benefits.

The land use system and its trend of change over time have not been beneficial to the soil resource. This was revealed by the analysis of some physical and chemical properties of soil samples collected from the major land use/ cover types (natural forests, cultivated lands, grazing lands and eucalypt plantations) in the watershed. The soils under natural forest cover showed the best soil properties for plant growth, while cultivated soils and eucalypt soils, in most cases, had the worst properties. This means that the land use practices and its trend of change over time, which is expansion of cultivated lands and increase of areas under eucalypt plantations, caused deterioration in the physical and chemical properties of the soils. Significant differences in many of the soil properties were also observed between soils in the upstream and downstream parts of the watershed. This suggests that any recommendation for soil management should be location-specific and the blanket recommendations for chemical fertilizer application and soil and water conservation, which are now the norm in Ethiopia, should be changed.

Unfavourable changes were also detected in the stream flow of the watershed. Over the past four decades, the total annual stream flow in the watershed decreased at a rate of 1.7 $mmyr^{-1}$, whereas the annual rainfall decreased only at a rate of 0.29 $mmyr^{-1}$. The decrease in the stream flow was more significant for the dry season, while the corresponding rainfall showed no discernible trend. Extreme low flows analysed at monthly and daily time-steps reconfirmed that low flows declined significantly with time. In contrast, the wet season rainfall and stream flow did not show any trends. Similarly, the extreme high flows analysed at monthly and daily time-steps did not reveal discernible trends. The declining trend in the dry season stream flow is mainly caused by the changes in land cover/use and/or watershed degradation. The stream flow is the only source of water to the local people for domestic consumption as well as for their

livestock. Hence, a set of measures aimed at reducing magnitudes of surface runoff generation and increasing groundwater recharge are essential to sustain the water resource and maintain a balanced dry season flow in the watershed. Besides maintaining water availability during the dry season, reducing magnitudes of surface runoff generation will help in mitigating the problem of soil erosion in the area.

Soil erosion by water from cultivated lands is a threat to agricultural production in the study area. This was revealed by a field-scale soil erosion survey that focused on rills and was conducted over two wet seasons and at two sites. Assuming that interrill erosion contributes 30%, soil losses were estimated at 18 $Mgha^{-1}$ in the upstream site and 79 $Mgha^{-1}$ in the downstream site. It is unlikely that the rate of soil formation can be as high as these rates of soil loss in the area. Hence, soil conservation measures are needed even to maintain the existing level of land productivity. A strong physical interdependence was observed between fields located in upstream and downstream positions in terms of erosion and sedimentation processes. This indicates that conservation in one farm will do little if the other farms in a higher position are not conserved. Soil erosion showed significant spatial and temporal variations. Thus, SWC measures that fit well into site-specific circumstances will be realistic and acceptable to the farmers, suggesting the need to change the existing wholesale approach in the country.

The farm households in the Chemoga watershed are therefore facing interrelated problems of resources degradation, which will exacerbate the poverty under which they are currently living. The people are poor, living on average annual household incomes ranging from Birr 779 in an upstream village to Birr 1692 (1.00 Birr ~ 0.125 $US) in a downstream village. Land and livestock are their fundamental bases of livelihood. Presently, land has become very scarce and landholdings of households have declined because of the increased population. Moreover, productivity of croplands has declined over time due to, as described by the farmers, ‘ageing of the land’, drought, soil erosion and their inability to use chemical fertilizers because of its high cost. There has also been a decreasing trend in number of livestock owned by households, while increase in the human population has caused an overall increase in the total livestock population in the communities. The latter has contributed to overgrazing, feed shortages and degradation of both grazing and cultivated lands.

The existing effort at resource conservation, which is focused on soil and water conservation in cultivated fields and is being undertaken as part of the extension package of the government, is not oriented towards bringing about meaningful results. A study on the extent of farmers’ participation in the conservation activities disclosed that the majority were disinterested in the conservation activities, specifically in the construction of *fanya juu* bunds in cultivated fields. The major reason for their disinterest was the perceived ineffectiveness of the bunds. Moreover, the conservation endeavour was not addressing the farmers’ priorities and preferences. The *fanya juu* bunds were being constructed in level and only moderately sloping lands (< 20% slope) for fear it would collapse if built on steeper slopes. Steeper slopes still under cultivation, which the farmers preferred to be treated, were left unattended and suffered from severe damage. The farmers were more willing to participate in the construction of diversion ditches and check dams than the *fanya juu* bunds. This was partly because the effects of the diversion ditches and check dams were more discernible to the farmers. This suggests that SWC technologies that yield perceivable effects (or benefits) are likely to be accepted and adopted. This was corroborated by the fact that the farmers planted trees in their privately operated lands for the immediate and tangible benefits it yields; that is, meeting their requirements for fuelwood and cash.

The households' requirement for domestic energy production is met exclusively from biomass. A survey in four sample villages in the watershed showed that fuelwood and cattle dung accounted for ~100% of the domestic energy consumption, with cattle dung contributing 34% of the total. The quantity of biofuel used varied between the villages and socioeconomic (income) groups. The destruction of natural forests and the consequent shortage of wood for fuel and other purposes has forced households to plant trees in privately operated lands. The privately planted trees accounted for the largest share of the total fuelwood used by the households. Moreover, the privately planted trees constituted an important source of cash. Number of trees planted showed variation between the villages and socioeconomic groups, which is attributable to physical and human factors and suggesting the need to take these into account in promoting (agro)forestry developments in the area.

In conclusion, the empirical studies reveal that there are interlinked problems of resource degradation in the Chemoga watershed. The physical interdependence between upstream and downstream land uses is also evident both at the watershed and sub-watershed scales. Given the interrelation of resources, interaction of the degradation problems and the apparent upstream-downstream interaction, the IWM approach is the appropriate option for effective and sustainable resource management in the area. The IWM approach enables an holistic view of the resources and use of different combinations of technologies to address the problem of resources degradation in an integrated manner. Effective and sustainable implementation of the IWM approach will require: microwatershed-level planning and pursuing of farmer-participatory processes, building upon indigenous knowledge systems and addressing of farmer priorities, ensuring of land tenure security, implementation of targeted and effective incentive systems and providing of client-oriented extension service. Though the empirical research findings, described above, are revealing the reality in the Chemoga watershed, they generally unveil the conditions in large parts of highland Ethiopia. Hence, the IWM approach will be an appropriate avenue for sustainable resource use and development in these areas.

Finally, lasting solutions to the problem of resources degradation in the Chemoga watershed and the country at large should however include a number of practical measures geared towards improving productivity of the agricultural sector, reducing human and livestock population pressures on the land, promoting development of the other sectors of the economy and alleviation of rural poverty.

Samenvatting en conclusies

Degradatie van natuurlijke hulpbronnen is een ernstig economisch probleem in Ethiopië. De hooglanden zijn het meest getroffen vanwege de hoge bevolkingsdruk van mens en vee. Conserveringspogingen in het verleden hebben meestal geen noemenswaardige resultaten opgeleverd. Daarom bestaat er dus een dringende noodzaak het probleem met nieuwe conserveringstrategieën, methoden en technologieën aan te pakken. Recente ervaringen uit andere landen hebben aangetoond dat geïntegreerd stroomgebiedbeheer (*integrated watershed management, IWM*) over het algemeen leidt tot een effectieve bescherming van de natuurlijke hulpbronnen en een verbetering van de middelen van bestaan in rurale gebieden. De doelstelling van dit proefschrift was het onderzoeken van de noodzaak tot en de mogelijkheden van invoering van de IWM methode in de hooglanden van Ethiopië. Het onderzoek werd uitgevoerd in het Chemoga stroomgebied, dat als een representatief stroomgebied in de noordwestelijke hooglanden beschouwd kan worden. Vanuit verschillende perspectieven en op verschillende schalen is onderzoek gedaan naar de omvang, de mate en de processen van degradatie, alsmede naar het huidige gebruik en beheer van hulpbronnen in het gebied. De voornaamste resultaten en conclusies worden hier kort gepresenteerd.

In het Chemoga stroomgebied zijn over de afgelopen 40 jaar veranderingen in landgebruik en vegetatiebedekking opgetreden. Landbouw was en is het voornaamste type landgebruik. De belangrijkste waargenomen verandering was de toename van het akkerbouwareaal ten koste van de communale graasgronden. Tegen de verwachting in was het bosareaal juist toegenomen. Het feit dat landbouw het belangrijkste en steeds belangrijker wordende landgebruik is, heeft gevolgen gehad voor bodems en de hydrologie van het stroomgebied. De geringe toename van het bosareaal heeft geen positieve gevolgen voor de duurzaamheid van het landgebruik, omdat de jonge aanplant vooral bestaat uit Eucalyptus ten behoeve van de houtproductie. Het is alom bekend dat Eucalyptus, naast economische voordelen, een aantal negatieve ecologische nadelen met zich meebrengt.

Het landgebruik en de veranderingen hierin hebben de bodem negatief beïnvloed. Dit is duidelijk geworden aan de hand van fysische en chemische analyses van bodemmonsters die onder de voornaamste landgebruiktypen in het stroomgebied verzameld werden (natuurlijk bos, akkerbouw, weide en Eucalyptus aanplant). De bodems onder natuurlijk bos hadden de beste eigenschappen voor plantengroei, terwijl akkerbouwgronden en bodems onder Eucalyptus aanplant in de meeste gevallen de slechtste eigenschappen hadden. Dit betekent dat het landgebruik en de toename in akkerbouw en Eucalyptus areaal een verslechtering van de fysische en chemische bodemeigenschappen tot gevolg hebben gehad. Vele bodemeigenschappen waren significant verschillend tussen de hoger gelegen locaties en de lager gelegen locaties binnen het stroomgebied. Dit wijst er op dat aanbevelingen voor verbeterd bodembeheer locatiespecifiek moeten zijn en dat de uniforme aanbevelingen voor kunstmestgebruik en voor bodem- en water conservering, die nu de norm zijn in Ethiopië, veranderd moeten worden.

De hydrologie van het stroomgebied werd ook beïnvloed door de veranderingen in landgebruik. Over de afgelopen 40 jaar is de jaarlijkse afvoer verminderd met 1,7 mm per jaar, terwijl de neerslag met slechts 0,29 mm per jaar afnam. De afname in afvoer is meer significant voor het droge seizoen, terwijl de regenval voor die periode geen significante trend laat zien. De maandelijks en dagelijks gemeten minimale afvoeren bevestigen dat er minder water beschikbaar is in het droge seizoen. In de regentijd daarentegen laten zowel regenval als de gemeten afvoer geen trends zien. Ook de maandelijks en dagelijks gemeten maximale afvoeren vertoonden geen veranderingen. De afname van de afvoeren in de droge tijd zijn voornamelijk veroorzaakt door veranderingen in landgebruik en vegetatie en/of door degradatie van het stroomgebied. Het water in de Chemoga rivier is de enige waterbron voor de lokale bevolking en veestapel. Een aantal maatregelen die de snelle afvoer verminderen en de grondwatervoorraad aanvullen zijn dus nodig om water als hulpbron te ondersteunen en om een gebalanceerde afvoer in de droge tijd te handhaven. Een verminderde snelle afvoer door oppervlakkige afstroming zal zowel de beschikbaarheid van water in de droge tijd waarborgen, alsmede erosieproblemen in het gebied verminderen.

Watererosie op akkerbouwgrond is een bedreiging voor de landbouwproductie in het studiegebied. Dit bleek uit een veldstudie naar bodemerosie op perceelsniveau, op een laaggelegen en een hooggelegen locatie. In dit onderzoek tijdens twee regentijden werden erosieverschijnselen in het veld gekarteerd en de hoeveelheden bodemverlies bepaald. De totale bodemerosie werd geschat op 18 Mg per ha in de hoger gelegen locatie en op 79 Mg per ha in de lager gelegen locatie. Deze erosie overschrijdt vele malen de natuurlijke bodemvorming en dus zelfs voor het op peil houden van de huidige landbouwproductie zijn bodem- en waterconserverings-maatregelen nodig. Een sterke onderlinge afhankelijkheid is waargenomen tussen de hoger en lager gelegen locaties voor wat betreft erosie en sedimentatieprocessen. Dit geeft aan dat de conservering van een bepaald gebied weinig zal uithalen wanneer de direct aangrenzende, maar hoger gelegen gebieden niet beschermd worden. Er bleek een belangrijke variatie in bodemerosie op te treden, zowel in ruimte als tijd. Bodem- en waterconserverings-maatregelen die goed passen in de locatiespecifieke omstandigheden zullen voor boeren realistisch en acceptabel zijn, wat inhoudt dat de huidige uniforme aanpak veranderd moet worden.

De boerenhuishoudens in het Chemoga stroomgebied worden geconfronteerd met meerdere, met elkaar in verband staande problemen van degradatie van hulpbronnen. Hierdoor wordt de al heersende armoede alleen maar verergerd. De mensen zijn arm en leven van een jaarlijks inkomen variërend van $ 90 per huishouden in een bovenstrooms dorp tot $ 200 per huishouden in een benedenstrooms dorp. Land en vee zijn de fundamentele basis voor hun levensonderhoud. Land is nu zeer schaars geworden en de grootte van de boerenbedrijven is afgenomen door de toegenomen bevolkingsdruk. Bovendien is de productiviteit van het land afgenomen als gevolg van - zoals boeren het uitdrukken - ‘het ouder worden van het land’, droogte, erosie en het onvermogen kunstmest te kopen vanwege de hoge kosten. Er is ook een afname in het aantal stuks vee per huishouden, maar door de groei van het aantal huishoudens is de totale veestapel toegenomen. Dat laatste heeft bijgedragen tot overbegrazing, tekorten aan veevoer en de degradatie van zowel weilanden als akkers.

De inspanningen binnen het voorlichtingsprogramma van de overheid, om hulpbronnen te beschermen middels bodem- en waterconservering in akkers, zijn niet zodanig gericht dat zij wezenlijke resultaten kunnen opleveren. Een studie naar de mate van boerenparticipatie in conserveringsmaatregelen laat zien dat de meerderheid er niet in is geïnteresseerd, met name niet in de constructie van de zogenaamde *fanya juu* - aarden dijkjes - in akkers. De voornaamste reden voor de desinteresse is de ondoelmatigheid van de dijkjes. Bovendien richt de poging tot bescherming zich niet op de prioriteiten en voorkeuren van de boeren. De *fanya juu* dijkjes worden alleen aangelegd in vlakke en matig hellende velden (<20%) uit angst dat ze op sterk hellende velden zouden doorbreken. Sterk hellende akkers, waarvan boeren bij voorkeur willen dat ze beschermd worden, werden niet behandeld en lijden grote schade. Boeren zijn meer gemotiveerd voor het meewerken aan de constructie van afvoerkanalen en dammetjes in erosiegeulen, dan voor het meewerken aan de *fanya juu* dijkjes. Deels is dit te wijten aan de voor de boeren beter zichtbare effecten van de afvoerkanalen en dammetjes. Dit zou betekenen dat bodem- en waterconserverings-maatregelen die in waarneembare effecten (of voordelen) resulteren meer kans maken op acceptatie en adoptie door boeren. Dit wordt bevestigd door het feit dat boeren bomen planten op hun velden: voor het oogsten van directe en tastbare voordelen, oftewel het voorzien in hun behoefte aan brandhout en inkomen.

Aan de energiebehoefte van huishoudens wordt uitsluitend voldaan door biomassa. Volgens een studie in vier dorpen binnen het stroomgebied voorzien brandhout en koemest samen voor 100% in het energieverbruik, waarbij koemest 34% bijdraagt. De hoeveelheid gebruikte brandstof variëert tussen dorpen en tussen verschillende sociaal-economische (inkomens) groepen. De vernietiging van natuurlijke bossen en de daaruit voortvloeiende tekorten aan brandhout en hout voor andere doeleinden hebben huishoudens gedwongen om bomen in de eigen velden te planten. Deze geplante bomen voorzien een huishouding van het grootste deel van het totale benodigde brandhout. Bovendien vormen deze bomen een belangrijke bron van inkomsten. Het aantal geplante bomen laat een variatie zien tussen dorpen en tussen sociaal-economische groepen en wat op de noodzaak wijst met deze factoren rekening te houden bij het promoten van agro-forestry ontwikkelingen in het gebied.

De uitgevoerde empirische studies laten zien dat er onderling verbonden problemen zijn op het gebied van de degradatie van natuurlijke hulpbronnen in het Chemoga stroomgebied. Ook de fysieke onderlinge afhankelijkheid tussen het landgebruik bovenstrooms en benedenstrooms is duidelijk geworden. Gezien het onderling verband tussen hulpbronnen, de interactie tussen de degradatie problemen en duidelijke bovenstrooms– benedenstrooms interactie, lijkt een geïntegreerd stroomgebiedbeheer (*integrated watershed management, IWM*) een geschikte optie voor een effectief en duurzaam beheer van de natuurlijke hulpbronnen. De IWM aanpak maakt een holistische benadering mogelijk van de beschikbare hulpbronnen en stimuleert het gebruik van verschillende combinaties van technologieën voor een duurzaam gebruik van de hulpbronnen. Toepassing van de IWM methodologie vereist: planning van maatregelen op het niveau van substroomgebieden, nadruk op boerenparticipatie, voortbouwen op lokaal aanwezige kennis, richten op prioriteiten van boeren, zekerstellen van eigendomsrechten, toepassen van een doelbewust en effectief stimuleringssysteem en voorzien in een klantgeoriënteerde voorlichtingsdienst. De bovenbeschreven empirische onderzoeksresultaten laten niet alleen de realiteit van het Chemoga stroomgebied zien, zij verduidelijken ook de situatie in grote delen van de Ethiopische hooglanden. Zodoende zal de IWM methode geschikt zijn voor het duurzaam gebruik van natuurlijke hulpbronnen en de economische ontwikkeling in deze gebieden.

Duurzame oplossingen voor het probleem van degradatie van hulpbronnen, in het Chemoga stroomgebied en elders in het land, moeten een aantal praktische maatregelen bevatten ter verbetering van de landbouwproductie, ter vermindering van de bevolkingsdruk door mens en vee, ter bevordering van de ontwikkeling van andere economische sectoren en ter verlichting van de rurale armoede.

Curriculum vitae

Woldeamlak Bewket was born on 14 February 1974 in Gojjam, Ethiopia. He obtained his first degree (B.A) in July 1994 from the Department of Geography, College of Social Sciences, Addis Ababa University. He graduated with the highest academic record (cumulative grade point average) of the year in the College, for which he was awarded the College's gold medal. Because of his performance, Woldeamlak was offered a permanent employment in the Department of Geography as a full-time academic staff member. After a year of service, he joined the graduate program of the Department for his second degree (M.A) by securing full sponsorship from the German Academic Exchange Service (DAAD). His academic merit in this program took him to the Department of Physical Geography at the Catholic University of Eichstaett, Germany, where he stayed for six months as a research scholar. In the graduate program, the performance of Woldeamlak was again outstanding. He defended his thesis in July 1998 before a public audience, and it was evaluated as *'Excellent'* by a board of internal and external examiners.

In April 1999, Woldeamlak was admitted to the Ph.D. program of the Erosion and Soil & Water Conservation Group, Department of Environmental Sciences, Wageningen University and Research Centre, The Netherlands. Since then, he conducted research on Integrated Watershed Management in Highland Ethiopia, which is the subject of this thesis. Woldeamlak has contributed articles to professional newsletters, presented papers in national and international conferences, authored research reports, and published articles in various international journals, some of which constitute this book. He can be reached at: wbewket@yahoo.com or Woldeamlak@geog.aau.edu.et