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Implications of Land Use and Land Cover Dynamics for Mountain Resource Degradation in the Northwestern Ethiopian Highlands

Land use and land cover changes that occurred from 1957 to 1995 in the Dembecha area, Gojam, in the Northwestern highlands of Ethiopia, were monitored using a geographic information system (GIS) and a remote sensing approach with field verification. The study area covers 27,100 ha and is representative of Gojam, which is known for its cereal production and export of surplus to major cities of the country. However, given the age-old tradition of clearing increasingly steeper land for cultivation and the lack of appropriate land use policies, productivity is currently heavily threatened by soil degradation. The results show that the natural forest cover declined from 27% in 1957 to 2% in 1982 and 0.3% in 1995. The total natural forest cleared between 1957 and 1995 amounts to 7259 ha. This is 99% of the forest cover that existed in 1957. On the other hand, cultivated land increased from 39% in 1957 to 70% in 1982 and 77% in 1995. The greatest expansion occurred between 1957 and 1982 (about 78%) and slowed down between 1982 and 1995 (only 10%) because almost no land was left for further expansion. Throughout the period covered by the study, cultivation encroached upon the very last marginal areas and steep slopes with gradients >30%. Such a dramatic change in 4 decades and the increasing proportion of completely degraded lands, from virtually nil in 1957 to about 3% in 1995, clearly indicates the prevailing danger of land degradation in the area.

Keywords: *Land degradation; land use change; land cover change; remote sensing; GIS analysis; landscape analysis; Ethiopia.*

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Introduction

Whatever their speed and magnitude, most land use and land cover changes are attributable to human activities and development or, to quote Hurni et al (1996, p 11), "soil erosion is as old as human history." According to FAO (1983), such human-induced processes are advancing at a much faster rate and now affect an immeasurably greater proportion of the Earth's land area. Major land use and land cover changes due to sedentary agriculture have been observed as occurring over different time spans. Some changes are of very short duration and of an exploitative nature, while others are long term and stable. According to Reenberg et al (1998), both types of change are primarily related to resource management strategies associated with agriculture and livestock grazing, which significantly influence land use and in turn cause land cover changes.

Analysis of land use and land cover changes over a given period of time can be done using aerial photography and satellite images at different scales. Models of land degradation can then be applied to indicate whether the land use and land cover changes were sustainable or unsustainable. Such analyses are essential for planning and decision-making focusing on actions related to environmental rehabilitation and various development programs as well as for awareness creation.

The study area covers about 27,100 ha and is assumed to represent Gojam, the traditional 'breadbasket of Ethiopia,' known for abundant cereal production and export of surplus to major Ethiopian cities. For the past 4 decades or so, Gojam has undergone dramatic land use and land cover changes, with the result that almost all land units have been converted to cultivated land (Figure 1). The age-old agricultural tradition of clearing the land (traditionally called *meret makinat*) was extensively practiced mainly in the first part of the study period (1957–1982). Combined with inadequate policies and institutional environments as well as other socioeconomic problems, this tradition has contributed to the present state of complete transformation seen in the area (Gete Zeleke 2000). As a result of these and other factors, the rates of soil and nutrient loss, mainly from cultivated lands, are extremely high, and soil productivity is decreasing rapidly. For instance, the long-term average annual soil loss from cultivated lands in the study area, where a 100 ha catchment served as a long-term monitoring site for the Soil Conservation Research Project (Hurni 1982), ranges from 130 to 170 t/ha/y (Herweg and Stillhardt 1999). The average annual suspended sediment yield from the unconserved catchment reached 61 t/ha/y (Bosshart 1997), the highest in the country.

Several questions arise with regard to the rapid land use and land cover changes and associated impacts in the area. First, what are the extent and degree of land use and land cover changes in the area in spatial and temporal terms? Second, what are the major consequences of these changes? Third, what will the future trends be in land use and land cover dynamics and associated results? Fourth, are these dynamics well perceived by relevant stakeholders? And finally, what are their implications at the regional, national, and international levels?

The present article mainly addresses the first of these questions, based on spatial and temporal analysis of land use and land cover changes from 1957 to 1995

FIGURE 1 By 1995, cultivation in the study area had reached the steepest slopes. Such marginal lands in the Ethiopian highlands are generally cultivated without conservation measures. (Photo by Gete Zeleke)

and investigation of possible implications for degradation of mountain resources in the study area. Land use changes in different types of landscape, trends in expansion of cultivated land, and associated results are presented. An additional aim is to create awareness among relevant stakeholders, such as community planners and decision- or policy-makers, about the speed and degree of land degradation and its long-term consequences. Eventually, of course, it is not only awareness that is important but improvements of policy, planning, and physical implementation, which are needed to protect potential agricultural soils in this part of the country from further deterioration through loss of soil productivity.

Geographical environment of the study area

The study area, covering about 27,103 ha, is located between 37°23′ and 37°35′E and 10°30′ and 10°45′N. It is situated 360 km northwest of Addis Abeba, the capital city of Ethiopia (Figure 2). Administratively, the area belongs to 4 districts (Weredas), most of it being in Dembecha Wereda. The northern, eastern, and western parts belong to Feres Bet, Macha Sinan, and Jabitehenan, respectively. The area is relatively densely populated, with an interpolated value of 125 persons/km^2 and an annual growth rate of 2.8% (Gete Zeleke 2000).

The study area is an extension of the typical agroclimatic profile of Mt. Choke, which is situated about 25 km northeast of the study area and extends from the cold and wet upper zones (Wurch, 4050 m) to the hot and moist/dry lower zones (Kolla, 1000 m) of the Blue Nile River Basin. The drop in altitude of about 3000 m over 75–100 km causes strong gradients in climate and hence in vegetation, land use, and living conditions. The area is located in the middle of these 2 extremes and extends from south to north over elevations of 1800–2800 m. It also has a very pleasant mountain climate, with an average annual rainfall of about 1600 mm and mean monthly temperatures that vary between 15 and 18°C. It is considered typical of the high-potential, intensively cultivated, mixed and ox-plow farmed cereal belt in the northwestern Ethiopian highlands.

Geologically, the area belongs to the Trapp series of Tertiary volcanic eruptions. Its topography is typical of volcanic landscapes, which were later deeply incised by streams, resulting in the current diversity of landforms. The soils have developed from volcanic ashes and reworked materials resulting from Tertiary volcanic

FIGURE 2 Location of the study area.

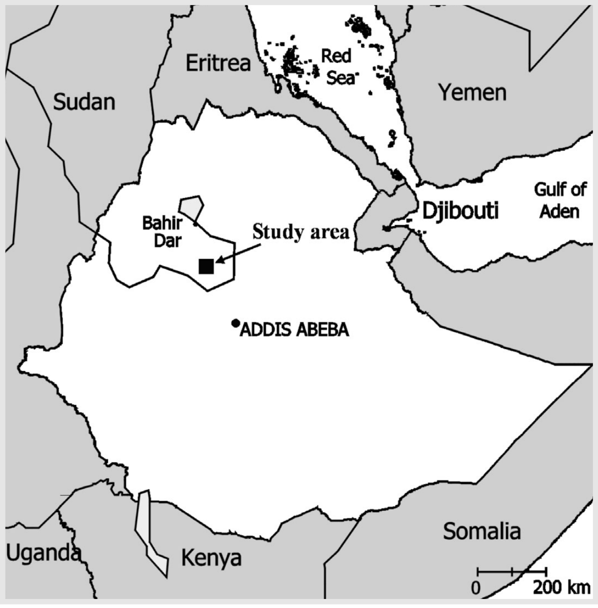


TABLE 1 Description of land use/land cover classes used for analysis of changes between 1957 and 1995.

Land use/land cover classes	Description
Cultivated land	This unit includes areas used for rainfed and irrigated cultivation, including fallow plots and a complex unit, ie, cultivated land mixed with bushes and trees, and rural homesteads.
Natural forest	Areas covered with trees forming closed canopy or nearly closed canopy (70–100%). This unit also includes woodlands (60–70% trees mixed with short bushes and open areas) and bamboo forests.
Plantations	Areas covered with planted trees, mainly *Eucalyptus* and *Juniperus procera* at different heights, mixed with regenerated trees and bushes, mainly *Acacia abyssinica,* and *Croton* species.
Grassland	Areas with permanent grass cover, used for grazing; usually communal.
Temporary grassland	Areas that are very flat and swampy in the rainy season and relatively dry (especially the periphery) during the dry season. Used as supplementary grassland; a good source of grass for the dry season (February to May).
Bushland	Areas covered with small trees, bushes, and shrubs. Scattered large trees can sometimes be found.
Shrubland	Areas covered with short shrubs and thorny bushes with little useful wood, usually stony with a very rugged microrelief.
Bare land	Areas that have little or no vegetation cover, mainly with classic gullies and exposed rocks.
Grass- and bushland	Areas covered with a mixture of grass and bush/shrubs in almost equal proportion and used as grazing land. Can be very easily converted to cultivated land.
Grass-, bushland and bare land	Areas with very shallow soils, covered partly with scanty grass, short bush/shrub, and exposed rocks. Normally consists of abandoned cultivated land, sometimes with gullies; used as local grazing land.
Small towns	Areas covered with urban settlement, including marketplaces and institutions such as schools and clinics.

eruptions and sedimentation processes. Nitosols are the dominant soil type, mainly on undulating to steep slopes. Relatively flat areas, and especially those closer to river valleys, are largely covered by well-developed Luvisols. As a result of degradation, the soils on steep slopes appear to have been downgraded to Regosols and Cambisols.

Materials and methods

Monitoring of land use and land cover changes in the study area was done at 3 intervals: 1957, 1982, and 1995. A geo-information modeling approach was used, employing aerial photo analysis (1957 and 1982), satellite image analysis (1995), and ground truth checking between 1996 and 1997. Data interpretation and analysis were conducted using ESRI's UNIX ARC/INFO GIS software (see also Solomon Abate 1994).

Prior to aerial photo interpretation, preliminary land use and land cover classes were established, and in the course of the interpretation, some classes were canceled while others were added (Table 1). Field checking was done between 1996 and 1997, using the results of the 1982 aerial photo interpretation. Sites with special points of interest that had few cover differences except quality and proportion were selected to verify the interpretation. About 10% of the study area was verified in the field. In addition, a 100-ha area within the study area had been continuously monitored since 1984 for land use and land cover changes (SCRP 2000).

Results of the photo analysis were transferred to a base map of the area (developed from a 1984 1:50,000 topographic sheet) using a digital pantograph. Later, the data were transferred to UNIX ARC/INFO GIS software via digitizer, and subsequent adjustments to a real-world coordinate system were made. Most of the analyses done thereafter were with cell-based modeling techniques using the Grid version of ARC/INFO.

For 1995, a digital satellite image (March 1995) covering 180×180 km^2 was used. From the digital data, a false color grid composite image was developed for systematic classification and assessment of land use and land cover changes. The image was adjusted using line objects on a 250,000 scale topographic sheet of the northwestern part of the country. Later, this image was clipped to the frame that covers the study area, and further adjustments with line objects on a 50,000 scale topographic map of the area were made until the alignment was satisfactory. Initially, a preliminary interpretation was made using vegetative biomass cover differences, and verification was done using the 1982 land use and land cover map as a reference. After the accuracy was checked by verifying objects—supplemented with 6 field (ie, ground truth) cross-sections and several free check points, as in the verification of aerial photo interpretation above—classification was done manually to adjust the preliminary interpretation. All calculations were done using GIS analysis, with figures rounded automatically to full percentages, except for values lower than 1%.

Results and discussion

Land use and land cover changes (1957–1995)

It was found that the natural forest cover declined from 27% in 1957 to 2% in 1982 and 0.3% in 1995. The total natural forest cleared between 1957 and 1995 amounts to 7259.3 ha, which is about 99% of the forest cover that existed in 1957 (Table 2; Figure 3). Major deforestation took place between 1957 and 1982, destroying about 94% of the 1957 forest cover. Conversely, cultivated land increased from 39% in 1957 to 70% in 1982 and 77% in 1995. Though the total expansion of cultivated land from 1957 to 1995 amounted to 95%, most of the expansion occurred between 1957 and 1982 (78% in about 2 ½ decades), with only 10% occurring from 1982 to 1995 because almost no land was left (Table 2; Figure 3). Nevertheless, the satellite image analysis and detailed field checking done in 1996–1997 showed that there is still a persistent push toward the remaining grass- and bushland in all slope classes (Figures 4, 5). The overall change was rather dramatic in the study area, where only a simple traditional ox-plow farming system is in use (Figure 6) and where there is no history of immigration into the area or any sort of mechanized farming within the time frame of the study.

Surprisingly, after such extensive deforestation, the total forest cover in 1995 increased to 2% due to afforestation (Map 3 in Figure 3) near the town of Dembecha (Sekela Maryam State Forest). From the point of view of environmental protection, this increase in forest cover by 1995 is a positive development, but for the community living near the afforestation site, the forest is an intrusion on their farm- and grassland and environmental protection is not a goal worth pursuing. There are 3 major reasons for this view among farmers. First, the forest belongs to the government and farmers have no direct benefit from it. Second, the forest was planted without full consultation with the community. Third, the forest is protected and farmers must keep their livestock away from it, which means more labor for the farmer and no direct share of the benefits from forest products, under threat of various penalties.

Consideration of the entire vegetative cover on the aerial photo shows that the area was more resilient in 1957 than in 1982 and 1995, partly as a result of the shifting cultivation system that was in use between 1957 and 1982, as confirmed in informal interviews with elders in the community. After 1982, shifting cultivation seems to have been replaced by intensification and an expansion of cultivation in marginal lands. As a consequence, some of the cultivated and grass- and bushlands on steep slopes have now become degraded and have very shallow soils. Abandonment of these areas has already begun and will undoubtedly increase: indeed, the proportion of degraded lands (bare land and grass-, bushland and bare land) increased from 0.1% in 1957 to 3% in 1995.

Land use and land cover changes in relation to slope and type of landscape

A significant observation about land use and land cover changes concerns the types of landscape affected by the changes that occurred from 1957 to 1995. Under normal circumstances, steep lands should be kept under forest cover or used for perennial crops but not for annual crop cultivation. As is visible in Figure 4a, cultivated land was mainly on gentle slopes (<30%) in 1957. The reverse was true in 1982 and 1995, with a dramatic increase up to 1982 (especially on steep slopes, ie, >30%) and a less dramatic increase up to 1995 because almost every steep slope had already been converted to cultivated land. Only rocky exposures, cliffs, some very marginal bushy areas, some grassland, and temporary swampy areas around rivers remained unchanged.

Figure 4b shows that the overall distribution of forest cover in all slope classes in 1957 was remarkable, with a relatively good share on slopes >20%. The latter is an indirect indication of a stable ecosystem. However, after only 26 years (1957–1982), almost all forests—including about 90% of the forest on steep slopes (>30%)—had been cleared from all slopes and converted to cultivated land. About 40% of the remaining forest cover in 1982 was on very steep slopes, which were in the vicinity of churches and not easily accessible. In 1995, too, except for a few patches of bamboo forests, the few remnant natural forests were around churches. This may illustrate the frequently made point about the importance of the Ethiopian Orthodox Church in preserving the country's forest genetic resources.

On the 12% of the area that is steep land (ie, >30%), the amount covered by cultivated land increased from only 19% in 1957 to 66% in 1982 and 79% in 1995. The overall expansion rate on these slope classes was 310%. Most of the expansion (239%) took place between 1957 and 1982. Except in a few parts, the remaining steep slopes that seemed to have soil cover were converted to cultivated lands between 1982 and

TABLE 2 Land use/land cover changes from 1957 to 1995. The cultivated land in 1957 consisted of fallow lands and a complex unit, ie, cultivated bush/scattered trees. The forestland included the woodland (in 1957) and bamboo forests (in 1982 and 1995).

Land use/land cover classes	Land use/land cover area coverage (in ha) and percentage (%)						Changes in land use/ land cover (in ha)		
	1957		1982		1995		1957–1982	1982–1995	1957–1995
	Area	%	Area	%	Area	%			
Cultivated land	10,692	39.5	19,031	70.2	20,893	77.1	+8338	+1863	+10,201
Natural forest	7342	27.1	452	1.7	82	0.3	−6889	−370	−7259
Plantations	0	0.0	10	0.0	525	1.9	+10	+515	+525
Grassland	4901	18.1	3865	14.3	3147	11.6	−1037	−718	−1754
Temp. grassland	952	3.5	565	2.1	516	1.9	−388	−48	−436
Bushland	1349	5.0	1030	3.8	103	0.4	−319	−927	−1246
Shrubland	25	0.1	309	1.1	332	1.2	+283	+23	+306
Bare land	17	0.1	69	0.3	168	0.6	+53	+99	+151
Grass- and bushland	1691	6.2	1149	4.2	400	1.5	−542	−749	−1291
Grass-, bushland and bare land	0	0.0	414	1.5	580	2.1	+414	+166	+580
Small towns	134	0.5	210	0.8	357	1.3	+76	+146	+223
Total	27,103	100	27,104	100	27,103	100			

Note: Temp. grassland is temporary grassland, which is swampy in the rainy season and partly dry in the dry season. Grass- and bushland is a mixture of grass- and bush/shrublands. Grass-, bushland and bare land is a degraded unit used mainly as grazing land (see Table 1).

FIGURE 3 Land use and land cover changes (1957–1995) in the Anjeni area, Gojam, Ethiopia. (Maps compiled by Gete Zeleke)

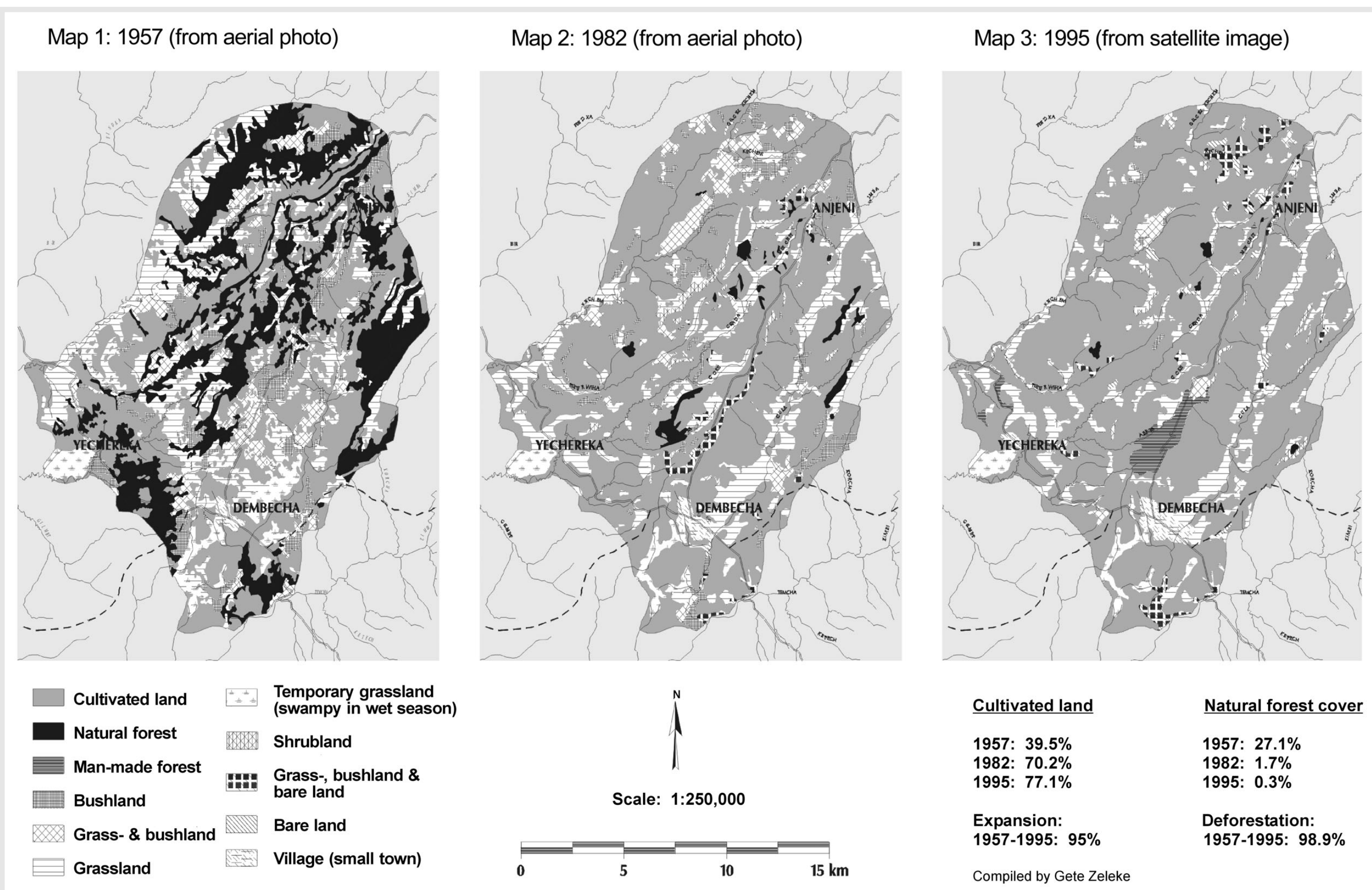


FIGURE 4 Amount of cultivated land (a) and forestland (b) and their distributions according to slope classes in 1957, 1982, and 1995.

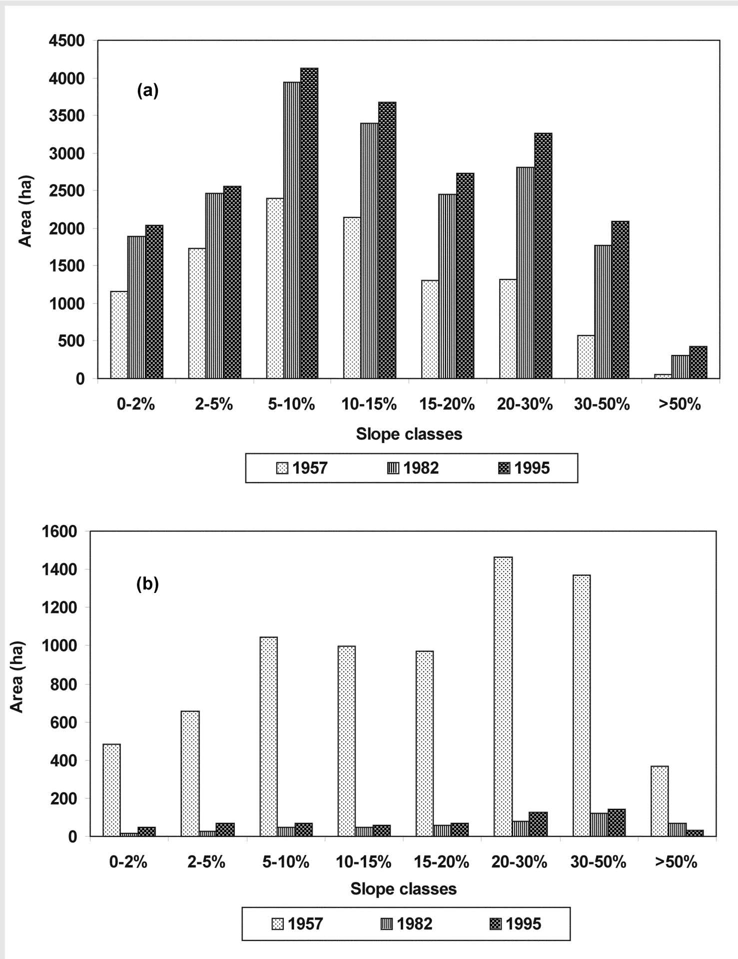
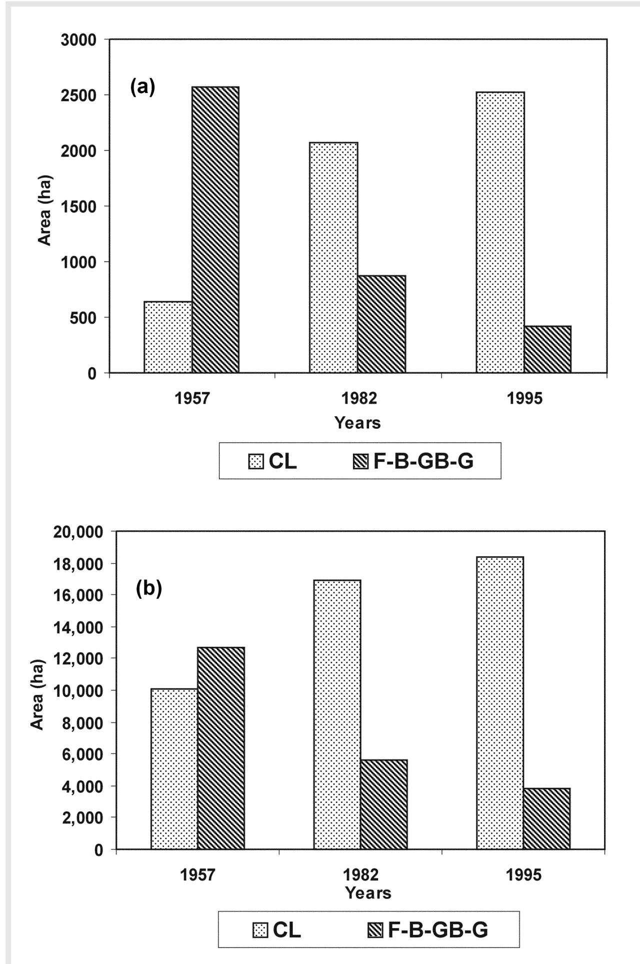


FIGURE 5 Amount of cultivated land (CL) and uncultivated areas covered with forest, bush, grass- and bushland, and grassland (F-B-GB-G) and their distributions on steep slopes >30% (a) and on gentle slopes <30% (b) in 1957, 1982, and 1995.



1995 at an expansion rate of 21%. On the other hand, combined coverage of forest, bush, grass- and bushland, and grassland (F-B-GB-G) on slopes >30% declined from 80% in 1957 to 25% in 1982 and 11% in 1995 (Figure 5a).

Expansion of cultivated land also took place on gentle slopes and flat areas (<30%). It increased from 42% in 1957 to 71% in 1982 and 77% in 1995. The overall expansion rate on these slope classes was high—about 82% (1957–1995)—leading to almost double the amount of cultivated area. On these slope classes, the combined area coverage of forest, bush, grass- and bushland, and grassland (F-B-GB-G) declined from 53% in 1957 to 24% in 1982 and 16% in 1995 (Figure 5b).

The field work study in 1996–1997 revealed that the remaining large portion of flat lands consisted mainly of areas around rivers exposed to seasonal flooding and swampy areas that are not currently suitable for crop cultivation. However, since the production system was based on claiming more land for cultivation rather than maximizing production per unit area, there was still a push toward these flat and swampy areas. Such a development threatens livestock production on the one hand and ecologically sensitive wetlands on the other.

Implications of the observed land use and land cover changes

The changes observed did not take place without negative consequences. For instance, as cultivated land was expanded at the expense of other land use and land cover units, grassland declined, resulting in less available fodder and a decrease in the number and quality of livestock. This led to a shortage of animals required for plowing and transport, as well as to a reduction of income and food from animals and their products. This series of related impacts indirectly affected the traditional land management system. When livestock and fodder was plentiful (in the 1950s), manuring was an important practice in the area. It increased soil fertility and hence production without extra cost to the farmer except for labor. After fodder availability and livestock had decreased, manuring (traditionally called *hura*) was gradually reduced. Moreover, manure is now in greater demand than ever not only because of the lower num-

FIGURE 6 Traditional ox-plow cultivation on a very steep slope. (Photo by Eva Ludi)

ber of livestock but also because its use as a source of fuel has increased due to reduction of fuelwood.

Strikingly, in 1996–1997, degraded land use and land cover classes indicated in Figure 3 as bare land and grass-, bushland and bare lands were used as grazing land. Livestock were forced to stay on these land units, especially during the cropping season, although there was little for them to feed on. This is one of the practices adopted by farmers when the population grows and land becomes scarce. The farming system remains traditional while most of the grasslands are converted to cultivated lands. In this case, both livestock and cultivation took over marginal lands, eventually leading to even more severe land degradation.

The conflicts in the farming system briefly mentioned here are clearly visible in the area. Communities have been under pressure for many decades and have tried to adapt to changing conditions. However, since their efforts have not been systematically supported by stable institutions and policies, the farming system currently appears to be in a very critical condition.

In the early period of the study, farmers practiced shifting cultivation, which allowed cultivated land to rest for 2 or 3 years to regain some of its potential. Moreover, cultivation was mainly on gentle slopes and flat areas. Over time, 2 major steps were taken, driven by population dynamics and lack of appropriate tenure and land management policies (Gete Zeleke 2000). First, farmers expanded onto steep slopes but still practiced shifting cultivation. Second, they reached an upper limit where they could no longer expand or practice shifting cultivation. They practiced abbreviated fallowing without any special land management measures to protect farmlands from the impact of upslope runoff and damage from torrential rainfall (Figures 1, 6).

This triggered 3 important processes that aggravate soil erosion. First, because of intensification, the physical hydrological properties of the soil were badly affected. For instance, infiltration was reduced and runoff was more easily initiated while aggregate stability decreased. The latter makes the soil less resistant to detachment. Second, at the onset of rainfall, about 77% of the area (ie, the proportion of cultivated land in 1995) is finely prepared for seeding and receives erosive storms for extended periods, without any protective cover. Third, almost all steep slopes, even those >100%, are under cultivation (see Figure 6). No special protection mechanisms exist except some traditional ditches, which in most cases aggravate runoff, especially on steep slopes. Because of these processes, the area is heavily threatened by land degradation. But planners and decision-makers in particular have not properly perceived this process, and the area has not been among the priority areas for soil conservation and environmental protection. This is a potential danger not only for the region but also for the country since most of the surplus cereals supplied to the cities are produced in this region. Kebrom and Hedlund (2000) express the same concern about loss of vegetation cover leading to lost ground.

The various effects of drastic land use and land cover changes in these areas will certainly have not only national but also international implications. Since the northwestern highlands of Ethiopia are the potential source of a supply of water and sediment to the Blue Nile, the impacts of change will soon be deeply felt by downslope users. The problem thus has a multinational dimension and requires an integrated effort before the agricultural potential of the area is lost beyond recovery (El-Swaify and Hurni 1996).

Conclusion

Though Gojam is naturally endowed with beautiful landscapes and soils with good potential, it has been continuously exploited for centuries and its present condition is very alarming. The spatial and temporal analysis of land use and land cover change presented here, though not an end in itself, clearly indicates the prevalence of serious land degradation and the related problems the area will face in the near future (see also Herweg and Stillhardt 1999). The changes have been dramatic for the traditional agricultural system, and the impacts are now highly visible. Vegetation cover has completely declined, the proportion of degraded lands has increased, the total annual soil loss rate is high (SCRP 2000), and soil productivity is dwindling. However, these processes have not yet been fully recognized by planners and decision-makers, who still believe that agricultural potential can be tapped as before. If this perception is not corrected and current trends averted, the great agricultural potential of this part of the country will soon be severely degraded, perhaps beyond recovery in some places.

In general, it can be concluded that the processes and associated problems observed have regional, national, and international implications (Hurni 1993). Hence, a change in scenario is required: a multilevel stakeholder approach to sustainable land management is needed (Hurni 1998). To this end, existing biophysical, socioeconomic, land policy, and institutional conditions need further careful investigation. Moreover, introduction of proper land management and tenure systems, population growth control mechanisms, and integrated environmental rehabilitation strategies must be given high priority, at the least to prevent existing potential from further deteriorating. The authors also believe that detailed investigations of household mechanisms for adaptation to the changes observed are essential for future action.

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