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Bezuayehu Tefera and Geert Sterk

Hydropower-Induced Land Use Change in Fincha'a Watershed, Western Ethiopia: Analysis and Impacts

The present article analyzes the land use dynamics caused by hydropower dam construction in 1973 in the Fincha'a watershed (1318 km^2), a tributary of the Blue Nile. Aerial photos (1957 and 1980) and an ASTER satellite image of 2001 were used to make 3 land use maps of the watershed using a geographic information system (GIS). The 239-km^2 water reservoir inundated 100 km^2 of grazing land, 120 km^2 of swamp, 18 km^2 of cropland, and 1.2 km^2 of forestland. In 2001, cropland covered 77% of the land potentially available for community use, indicating that there is hardly any free land available for expansion to accommodate new farmers. Relocated communities operate on relatively small parcels of land situated either on steep slopes or in flood-prone areas. Consequently, they exhaustively utilize the trees available on their holdings, and convert grassland and bushland to cropland, without applying sufficient soil conservation measures. Farmers resettled at or near bodies of water and swamps, however, are affected by seasonal fluctuations of water levels that very often inundate croplands, grazing land, and homes. The demand for cropland and grazing land is increasing as reservoir and swamp areas expand and new families are created. Soil erosion in steep areas can no longer be reduced in the traditional farming system. These enforced land use changes, combined with a lack of appropriate land management practices, may increase erosion and reservoir sedimentation. This could affect food security and electric power production in the near future.

Keywords: *Land use change; remote sensing; water reservoir; GIS; Ethiopia.*

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Introduction

Dams have been built for thousands of years for electricity, irrigation, flood control, and water supply (WCD 2000). Despite their benefits, they are also associated with loss of agricultural land, forests, and grasslands in upstream watershed areas due to inundation of the reservoir area (WCD 2000; Bird and Wallace 2001), alteration of traditional resource management practices (Roder 1994), displacement and impoverishment of people, and inequitable sharing of environmental costs and benefits (Bartolome et al 2000).

Fincha'a dam was constructed in 1973 as a strategy for fostering economic growth in Ethiopia through generation of hydroelectricity, irrigation, fishery, and tourism (HARZA Engineering Company 1965, 1975). Currently, of the 478 MW hydropower capacity generated in the country, this power plant generates 128 MW (Assefa 2003), supplies water to a sugar factory downstream, and has created new economic activities such as fishery.

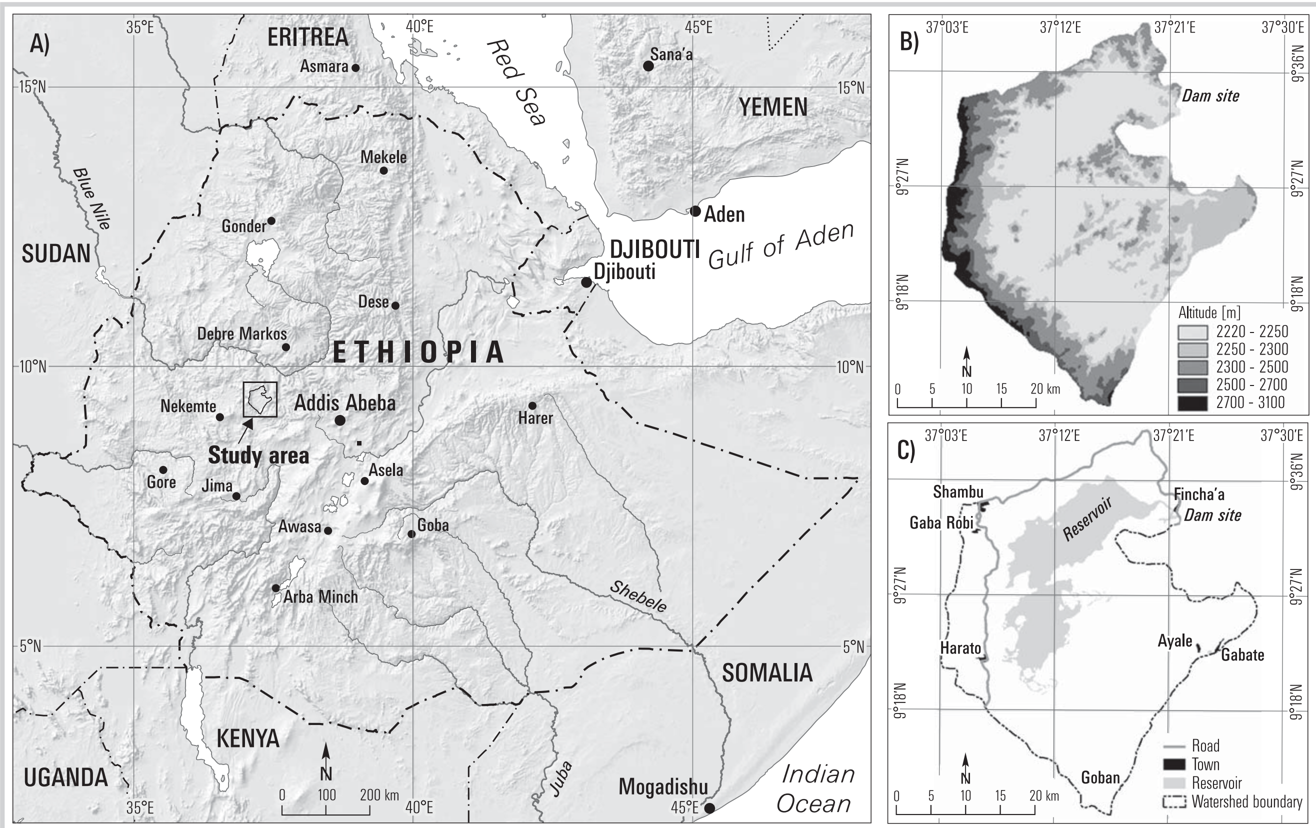
Notwithstanding these benefits, studies done by the Oromiya Agriculture and Development Bureau (OADB 1996) and Assefa (1994) have shown that Fincha'a reservoir has inundated large areas with different land use types and driven people from their original places of settlement. The displaced people have mostly moved to available areas within the watershed, and have often taken up agricultural activities on steep and marginal areas within the watershed. This process of migration and new agricultural activities, in combination with normal population increase, may have caused detrimental land use changes and aggravated the rate of environmental degradation in the upstream portions of Fincha'a watershed (Assefa 1994).

Land use changes have been extensively researched owing to their key role in environmental goods and services (Xu et al 2005). They are a very important aspect of global change. When they are aggregated globally, they directly impact biotic diversity, contribute to local and regional climate change, are the primary source of soil degradation, and, by altering ecosystem services, affect the ability of biological systems to support human needs (El-Swaify 2002). Land use studies in Ethiopia, however, have mainly focused on forest cover and deforestation rates at national level (Mesfin 1985; EFAP 1994).

So far analyses of comprehensive land use dynamics at watershed level in general have been scarce in Ethiopia. Hence, knowledge of spatial dynamics, the magnitude of different land use types, factors driving the changes, and the implications of these changes is minimal. Recent watershed-based land use studies in different parts of the country, however, show that there has been an increase in cropland at the expense of forests and grassland due to population growth and the land reform of 1975 (Solomon 1994; Gete 2000; Woldeamlak 2003). Cropland expansion in Mettu (Solomon 1994) was relatively less (32%) than at the other study sites, as a result of increased coffee plantation in forested areas.

Studies of land use dynamics in watersheds where a reservoir was created have not been carried out previously. The objective of this study was, therefore, to analyze land use changes in Fincha'a watershed over a

FIGURES 1A–1C A) Location of Fincha'a watershed in western Ethiopia. (Map by Andreas Brodbeck). B) Study site with major infrastructure. (Map by Bezuayehu Tefera and Mulugeta Tadese). C) Topography of Fincha'a watershed and location of dam site. (Map by Bezuayehu Tefera and Mulugeta Tadese)



period of 45 years, and describe the possible causes and implications of these changes for the community at large and the hydropower dam itself. Our aim was to answer the following question: How did construction of the dam and the subsequent increase in the size of the lake affect land use changes in Fincha'a watershed? It was also hypothesized that backwater flow has reduced the area of good potential farmland, but the area of marginal farmland has increased as a result of conversion of forest and grasslands on less suitable areas.

Materials and methods

Site description

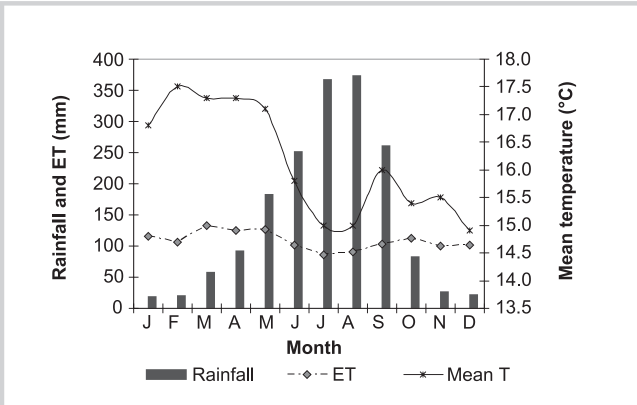
Fincha'a watershed is located between 9°10′30″ and 9°46′45″ N latitude and 37°03′00″ and 37°28′30″ E longitude (Figure 1A). It covers an area of about 1318 km^2. Elevation in the watershed ranges between 2200 m and 3100 m. Most of the area (80%) is a wide rolling plateau situated at 2200–2400 m (Figure 1B). The higher parts of the watershed near the boundary (where the drainage of all the streams begins) as well as the elevated parts in the middle, which are isolated outcrops, are composed of Quaternary volcanic material. A small part of the watershed at the northeastern part consists of Adigrat sandstone formation. The dominant soils are clay, loam, and clay-loam.

The Fincha'a hydropower dam (Figure 1C) has a 340 m crest length and a height of 20 m above the lowest foundation level (HARZA Engineering Company 1975). From 1973 to 1986 Fincha'a River alone supplied water to the hydropower scheme, but in 1987 Amarti River was diverted to Fincha'a through a tunnel.

Weather data were available from a station at Shambu town, which is situated in the middle part of the watershed (09°34′ N latitude and 37°06′ E longitude and elevation 2430 m). The average annual rainfall over the period of 1970–2003 was 1823 mm. About 80% of the annual rain falls between May and September. The monthly mean temperature varies from 14.9°C to 17.5°C. The average annual Reference Evapotranspiration (based on Penman-Monteith) is 1320 mm, with low monthly variations (Figure 2).

Population density in 2001 was 98 people per km^2, with an average family size of 8 people per household. In 2002 the average landholding of the unaffected communities was 2.5 ha, with an average per capita landholding of 0.3 ha. But information shows that the holdings of people affected by the dam

FIGURE 2 Climate conditions in Fincha'a watershed, western Ethiopia. (Source: National Metrological Service Agency 2004)



are smaller than the holdings of those who are unaffected. Integrated crop–livestock production is the main agricultural system in this watershed. Farmers whose villages have not been intentionally relocated leave some 20 to 45 stands of trees per ha on their own farms and homestead areas. The trees are regularly pruned and the biomass is used for soil fertility enhancement, fuelwood, and construction. Besides, many farmers practice homestead and farm boundary plantation.

Land was privately owned before the 1975 land reform. After this reform, land became state property, with rights of use given to the farmers. Forests and grazing lands became open access areas, leading to encroachment and overgrazing.

TABLE 1 Land cover and land cover change for the 6 land use classes in Fincha'a watershed in 1957, 1980, and 2001.

Land use class	Description
Water body	Area completely inundated by water.
Cropland	Area used for cultivation, including fallow plots and complex units such as homesteads.
Swamp	Flat and swampy area (locally called *raatuu)* during both wet and dry seasons; mainly covered with grass.
Grazing land	Area covered with grass, bushes, and trees, and used for grazing; usually communal.
Forest	Area covered with natural and plantation trees, sometimes mixed with enrichment plantations, forming nearly closed canopies with 70–100% cover.
Town	Area covered by urban land use.

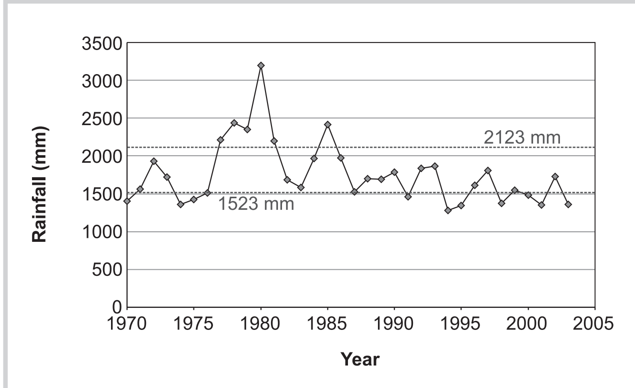
Methodology

Geographic information systems (GIS) and remote sensing (RS) technologies were used to analyze the spatio-temporal status of land use in Fincha'a watershed. A combination of aerial photographs and a satellite RS image was used. Aerial photos for 1957 (taken in December; 57 photographs) and 1980 (taken in January; 60 photographs) with base scales of 1:50,000 were obtained from the Ethiopian Mapping Agency (EMA). An ASTER RS image of green, red, and near-infrared bands from January 2001 (15-m resolution) was obtained from the Internet. While the ASTER image was used due to the absence of recent aerial photographs, the aerial photos were the only sources of information for earlier periods. The timing of all 3 data sources was such that they represented the dry season with minimal cloud cover, and could be considered comparable in terms of land cover conditions (eg bare conditions on cropland).

The aerial photographs were orthorectified and visually interpreted using a mirror stereoscope to derive the maps for land use that existed prior to and 6 years after the creation of the dam. Six topographic maps (1980 edition) at a scale of 1:50,000 were obtained from EMA and used to delimit and cut out the study watershed. A false color composite of the Terra ASTER image was created and geo-referenced on UTM (Universal Transverse Mercator) projection. The rectified image was then interpreted in IDRISI GIS using the supervised classification method. In this method spectral signatures were developed from specified locations that were verified as having a particular land use type, defined as training sites. A vector layer was then digitized over a raster scene to separate different land use types. A global positioning system (GPS) was used to collect data from the training sites.

Preliminary land use classes were defined prior to aerial photo interpretation, with some modifications made while interpreting the satellite image. Using aerial photographs, 8 land use classes were identified: water body, cropland, swamp, grassland, bush-covered grassland, forest, plantation, and town. But the ASTER image was less detailed, which resulted in poor differentiation between forests and plantations, and between grassland and bush-covered grassland. Hence, we merged forest and plantation into one class and called it forest, and grassland and bush-covered grassland were also combined into grazing land. Both land use types are being used for grazing and sparsely populated by bush trees. Field observations showed that degraded lands were of minimal importance in the watershed compared to other land use types, and their study was thus less useful. Finally, 6 classes were used for the aerial photo and ASTER image interpretations (Table 1).

FIGURE 3 Annual rainfall in Fincha'a watershed, western Ethiopia. Space between dotted lines indicates the range of assumed normal variation in annual rainfall.



Analysis of annual rainfall was carried out to determine the amounts of rainfall in the year prior to the remote sensing datasets of 1980 and 2001. Only rainfall data from 1970 to 2003 were available, so no information on rainfall prior to the 1957 dataset existed. This analysis was done to determine whether rainfall affected land use in the watershed area. It was expected that a relatively wet year prior to the land use classification could have resulted in expansion of the water body and perhaps more swamp land than when the antecedent rainfall was below average. Overlays of the 1980 and 2001 water body areas on the 1957 land use map were made to determine the spatial distribution and magnitude of the land use types directly affected by the reservoir.

Altogether, 5 elderly persons (3 from affected and 2 from unaffected parts of the watershed) served as key informants to provide information that was used to complement interpretation of the aerial photos and satellite image. They also helped to explain the dynamics of land use changes and the environmental and economic effects of these changes following creation of the dam.

Results

The mean annual rainfall at Shambu station was 1823 mm, but it showed some variation over the period of analysis (1970–2003) (Figure 3). The obtained coefficient of variation was 22.5%, indicating relatively low variation. Annual rainfall ranged from 1281 mm in 1994 to 3195 mm in 1980. We assumed a range of 600 mm around the average (1523–2123 mm) as being normal fluctuations. Years with rainfall above or below this range were considered abnormally wet or dry, respectively. Wet years occurred from 1977 to 1981, and another wet year was experienced in 1985. Dry years occurred around 1975, which coincides with the famine that struck Ethiopia, and several dry years have been experienced since 1987.

A general decline in annual rainfall can be observed following the peak rainfall in 1980. The year prior to the aerial photographs of 1980 was very wet, with a total rainfall of 2347 mm. The year prior to the ASTER RS image of 2001 was relatively dry, with annual rainfall of 1484 mm. Land use for the 3 years (1957, 1980, and 2001) was classified according to the classes defined in Table 1. The areas covered by the different land use classes are shown in Table 2. The same results were plotted in Figure 4, excluding the class 'town' to improve clarity of the maps.

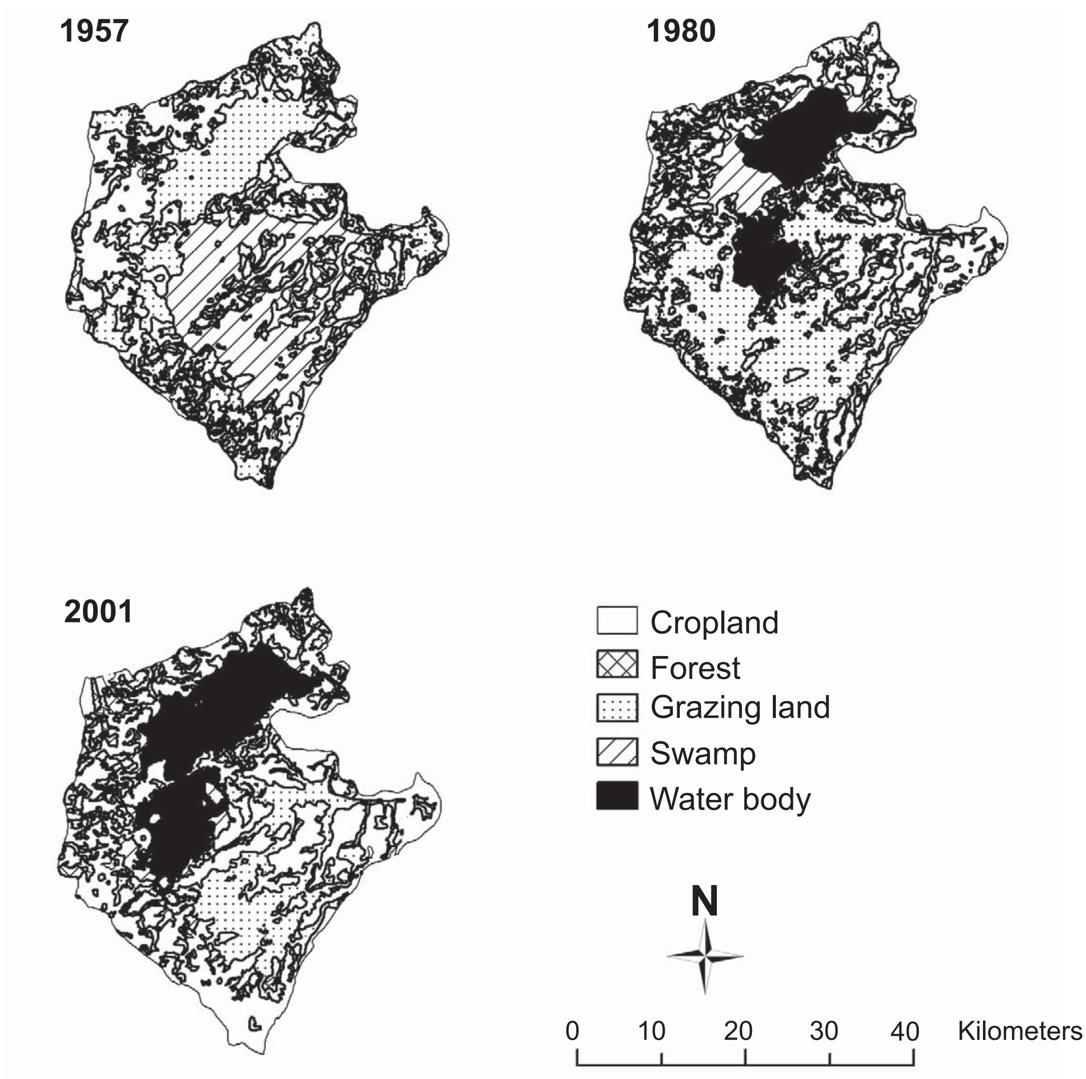
Water body

There was no significant body of water in this watershed before the impoundment period. The interpretations of the 1980 aerial photos showed that 7 years after the dam had been constructed, about 151 km^2 (11.5%) of the

TABLE 2 Major land use classes on potentially available land in Fincha'a watershed in 1957, 1980, and 2001.

	Area in 1957		Area in 1980		Area in 2001		Area change (km^2) from	
Land use	km^2	%	km^2	%	km^2	%	1957 to 1980	1980 to 2001
Water body	0.0	0.0	151.1	11.5	239.3	18.2	+151.1	+88.2
Cropland	403.3	30.6	478.8	36.3	607.1	46.1	+75.5	+128.3
Swamp	286.1	21.7	376.6	28.6	95.5	7.2	+90.5	–281.1
Grazing land	555.2	42.1	272.9	20.7	332.2	25.2	–282.3	+59.3
Forest	70.5	5.4	34.1	2.6	37.9	2.9	–36.4	+3.8
Town	2.5	0.3	4.1	0.3	5.6	0.4	+1.6	+1.5
Total	**1317.6**		**1317.6**		**1317.6**			

FIGURE 4 Land use maps of Fincha'a watershed (western Ethiopia) for 1957, 1980, and 2001. (Maps by Bezuayehu Tefera and Geert Sterk)



watershed had been converted to water bodies, which is equivalent to the estimate given by the HARZA Engineering Company (1975). This value increased to 239.3 km^2 (18.2%) by 2001, a net increase of 88.2 km^2. From the 1980 land use map it appeared that there were 2 major water bodies (ie, the upper part, known as Coomman, and the lower part, known as Doonje) that were physically separated (Figure 4) by a ridge approximately 8 m high and 1 km wide (HARZA Engineering Company 1966). The ridge acts as a natural dam and created a large area of seasonal swamp in the Coomman area. Analysis of the RS image, however, showed unified water bodies. This was obviously a result of increased reservoir levels following diversion of the Amarti River into Fincha'a in 1987, which was effected by means of a 16 m high dam and a tunnel 1500 m long and 3 m in diameter (EELPA 1982).

Cropland

This category also includes rural villages (dispersed settlements) and homestead plantations because it was difficult to treat them as a separate land use type. Most homestead areas are set in such a way that tree plantation and cultivation are intermingled. Generally, cropland increased from 403 km^2 in 1957 to 478.8 km^2 in 1980 and 607 km^2 in 2001—a net increase of 51%. Overlay analysis of the water body in 1980 and the land use map of 1957 show that 11.5 km^2 of cropland situated on the western, northern, and eastern sides of the lower lake were inundated. The water body that existed in 2001 inundated an additional 6.5 km^2 of cropland situated in the western and northern parts of the lower lake. This makes a total loss of 18 km^2 of cropland due to the creation of the hydropower dam in the watershed area. Most cropland was situated in relatively flat areas in 1957 and 1980. In 2001, however, many steep lands in the southern and western parts of the watershed were converted to cropland.

Grazing land

The area of grazing land decreased by 50.8% between 1957 and 1980 but increased by 21.7% at the expense of swampland between 1980 and 2001, which means a net decrease of 40% between 1957 and 2001. About 94.2 km^2 of grazing land in the Doonje area and the western part of Coomman were inundated between 1980 and 2001, amounting to a total of 100 km^2 of grazing land lost due to the creation of the dam in 1973 and the Amarti River diversion of 1987. Recently, however, a reduction in the amount of runoff entering the reservoir has reduced the size of swamp land, leading to expansion of grazing land. Grazing land was situated in depressed areas of the watershed, where seasonal waterlogging occurred, and along the water divide lines in the western and southwestern parts of the watershed, on the hills, and along embankments of streams and rivers.

Swamp

Many of the flat areas on the upper part of the lake (Coomman) used to be seasonal swamp before the creation of the dam. This land cover type showed a pattern of increase in the first period and decrease in the second period, ie an increase of 90.5 km^2 between 1957 and 1980 but a decrease of 281 km^2 between 1980 and 2001. About 44.5 km^2 of swamp in the Coomman area were inundated between 1980 and 1957. But an additional 75.4 km^2 in the same land use category, situated in the western, southern, and eastern parts of the current lake, were inundated between 1980 and 2001. Consequently, leaving much of its original location for a water body, the swamp engulfed a large area of grazing land and cropland, mainly in the southern and western parts of the watershed, between 1957 and 1980. Analysis of the RS image of 2001 showed that the swamp shrank considerably again in favor of grazing land, the spatial distribution being at the fringes of the water body following stream courses and depressions.

Forest

There was a general lack of forest cover in the watershed area before 1957. The remaining forest cover changed from 5.4% in 1957 to 2.6% in 1980 and 2.9% in 2001, ie a net loss of 46%. Consequently, about 0.9 km^2 of the forests situated around the Doonje area was inundated. An additional 0.3 km^2 situated in the western and northern parts of Doonje was inundated between 1980 and 2001. The forests were mainly situated along water divide lines in the western and southwestern parts of the watershed, hillsides, embankments of streams and rivers, and adjacent to towns and settlement areas. In general, rapid forest reduction was detected between 1957 and 1980, perhaps due to expansion of cropland and grazing land and to collection of wood for household consumption, construction, making farm implements, and providing cash income. By 2001 forest cover had increased compared to 1980. This could be due to reforestation activities carried out in forested areas, hills, and settlements in the 1980s.

Town

Urbanization as land cover, in the form of built-up or paved areas, covers 0.3 to 0.4% of the watershed area. Construction of the hydropower dam and population growth have contributed to the increase in this category. The construction of the dam and electrification have created limited job opportunities and attracted people to the towns. Towns showed mixed impacts on land use. On the one hand urbanization affected land use by increasing use of forests for construction and fuelwood, but on the other plantation activities were practiced in and around the towns.

Discussion

Land use changes

In this section the major land use changes, factors underlying these changes, and opportunities available for the community in Fincha'a watershed are discussed. The major land use changes were the creation of 239.3 km^2 of water body that inundated 18 km^2 of cropland, 120 km^2 of swamp, 100 km^2 of grazing land, and 1.2 km^2 of forest between 1957 and 2001. In the same period, the area of cropland increased by 203.8 km^2, mainly at the expense of grazing land and forest. Recently, the dynamics in the area and location of swamp and grazing land have become unusual for the community as well as the power company. Before 2001, many people thought that the reservoir area was expanding, but after 2001 it receded in all directions due to reduction in annual rainfall. The interface between swamp and grazing land fluctuates, depending on the magnitude of rainfall and the gradient of the reservoir bed. In the inundated area, a low longitudinal gradient of 1:476 m/m was determined between the dam and the remotest part of the reservoir. This could be the main reason for such a large reservoir area of

TABLE 3 Major land use classes on potentially available land in Fincha'a watershed in 1957, 1980, and 2001.

Land use	1957		1980		2001	
	km²	%	km²	%	km²	%
Cropland	403.3	39.0	478.8	60.6	607.1	76.8
Grazing land	555.2	53.8	272.9	34.5	139.8[a)]	17.7
Forest	70.5	6.8	34.1	4.3	37.9	4.8
Town	2.5	0.2	4.6	0.6	5.6	0.7

[a)] Of the 332 km² of grazing land detected in 2001, about 192.4 km² was seasonal grazing land and only 139.8 km² was permanent grazing land.

239 km² to be impounded by a dam only 20 m high with a crest length of 340 m.

The areas of water body, swamp, and grazing land in the lower part of the watershed vary depending on the annual rainfall. Given these fluctuations, it is useful to make a distinction between land that is potentially available to the community, and land that is not suited for permanent agriculture (ie the reservoir and swamp land). Parts of the latter class could be used for grazing during relatively dry years, when the extent of the reservoir and the swamp is limited. Since the amount of annual rainfall that occurred before 1970 is unknown, it was assumed that the 1957 classification of swamp area represented the area of non-suitable land before the dam was constructed. After construction of the dam, the year 1980 had a peak rainfall amount, and it was assumed that the land use classification of that year gives a good estimate of the boundary between potentially available land (well-drained area) and land unsuitable for farming in the watershed. Accordingly, the total area that was potentially available for community use was 1032 km² (78%) in 1957 but shrank to 790 km² (60%) by 1980. In other words, after construction of the dam 40% of the watershed was no longer available for permanent cropping and grazing. The land use types potentially available for community use are indicated in Table 3, based on the above results.

The area of potentially available land before and after the construction of the dam was used to reclassify the major land use classes (Table 3). In this way, a dramatic increase in cropland and a sharp decrease in permanent grazing land become apparent. These changes are quite similar to what happened in Dembecha, where nearly all available land was used for rainfed crop production already in 1995 (Gete 2000). The relocated communities operate on relatively small amounts of land situated either on steep slopes or in flood-prone areas. Consequently, they exhaustively utilize the trees available in their holdings, and convert grassland and bushland to cropland without applying sufficient soil conservation measures. Those farmers whose resettlements are situated near bodies of water and swamps, however, are affected by seasonal fluctuations in water levels that very often inundate cropland, grazing land, and homes. According to information obtained from elderly people, animals as well as people drown in mud and water. The demand for cropland and grazing land becomes more pressing when the reservoir and swamp areas expand and new families are created. Reduced fallowing and continuous cropping have become common practices in the watershed.

Implications of the reservoir in the watershed

Based on susceptibility to erosive rainfall, land use in Fincha'a watershed was categorized in 4 groups: 1) areas that are bare when erosive rain occurs and are exposed to accelerated erosion (ie cropland); 2) areas that have a relatively better vegetation cover but are exposed to indiscriminate tree cutting and overgrazing (ie grazing land); 3) areas with better vegetation cover all year round but subjected to limited encroachment (ie forest); and 4) the water body and swamp. Thus, the proportion of the watershed exposed to possible maximum soil loss was cropland, amounting to 31% in 1957, 36% in 1980 and 46% in 2001. This shows that the area potentially subjected to accelerated erosion increases from time to time. Indeed, rill and gully erosion are abundant forms of erosion on cropland and grazing land. Field observations showed a high sediment influx into the water body (Figure 5), which caused a reduction of the lake's surface area and volume.

Despite these signs of degradation, reforestation and soil and water conservation activities are lacking in the watershed. At the receded parts of the reservoir, many farmers have already started to grow potatoes and maize, and graze their animals. This situation was not detected using the satellite image because these practices must have started after the image was taken. The population of floating grasses growing from the floor of the lake has recently increased, perhaps due to the enhanced sediment influx. This may result in more evapotranspiration losses and reduced electric power generation.

FIGURE 5 Sediment load transported by a stream into the reservoir in Fincha'a watershed, western Ethiopia, February 2003. (Photo by Bezuayehu Tefera)

According to the key informants, the reservoirs and swamps have had negative economic and environmental impacts on the community in the watershed area. For instance, animals and sometimes human beings drown in the swamps and reservoir. Streams often burst and cause habitat destruction. When the watershed had good vegetation cover, clean water used to be obtained from streams and springs the whole year round, but today the water supply from these sources is short-lived. The demand for cropland and grazing land becomes more pressing when the reservoir and swamp area are expanding and new families are created. The traditional farming system is no longer sufficient to reduce soil erosion in steep areas.

Conclusions

The creation of the hydropower reservoir in Fincha'a watershed has claimed about 239.2 km^2 of land, including 100 km^2 of grazing land, 18 km^2 of cropland, 1.2 km^2 of forest and 120 km^2 of swamp. Though expansion of cropland into grazing land and forestland is a common trend elsewhere in the country (Solomon 1994; Gete 2000; Woldeamlak 2003) and other developing countries (Kammerbauer and Ardon 1999; Semwal et al 2004), the creation of the reservoir in Fincha'a watershed enhanced the expansion of cropland. This was most likely caused by dislocated inhabitants who undertook resettlement on their own in upstream parts of the watershed by encroaching into forests and grazing lands. The land reform of 1975 probably contributed to some extent to land use changes in this watershed because following this reform, grazing lands and forests were freely accessed for various uses. Consequently, of the land potentially available for community use, cropland covered 77% in 2001, indicating that there is virtually no possibility for further expansion to accommodate new farm families. Since there is no policy on land use planning in the watershed, further undesired land use changes are imminent.

In general, land use changes in Fincha'a watershed are mainly the result of construction of the hydropower dam, population pressure (induced by forced migration and normal growth), and annual rainfall fluctuations.

The relocated communities operate on relatively small amounts of land situated either on steep slopes or in flood-prone areas. Consequently, they exhaustively utilize the trees available in their holdings, and convert grassland and bushland to cropland without applying sufficient soil conservation measures. Those farmers who resettled around water bodies and swamps, however, are affected by seasonal fluctuations in water levels that very often inundate cropland, grazing land, and homes. According to information obtained from elderly people, animals as well as people drown in mud and water. The factors responsible for land use change in this watershed have been interacting in a very complicated way; the overall implication could be on-site soil erosion and off-site sedimentation of water reservoirs. Therefore, changes in land use in this watershed affect the livelihood of the community and will also affect the ability of the dam to deliver the planned economic benefits. Fincha'a River is a tributary of the Blue Nile. The on-site and off-site effects of this watershed may thus have local, national, and international dimensions. Searching for solutions calls for cooperation at all levels.

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AUTHORS

Bezuayehu Tefera
Oromiya Agriculture and Rural Development Bureau, PO Box 21118, Code 1000, Addis Abeba, Ethiopia.
bezuayehto@yahoo.com

Geert Sterk
Erosion and Soil and Water Conservation Group, Wageningen University, PO Box 47, 6700 AA Wageningen, The Netherlands.
Geert.Sterk@wur.nl

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