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# Land Cover Change and Gully Development Between 1965 and 2000 in Umbulo Catchment, Ethiopia

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*Land cover change studies examine the status of land to explain physiographic and socio-economic processes, causes and effects, and environmental implications. The present paper relates land cover change in a food-insecure catchment to development of gullies, particularly their position in the landscape as well as the history of gully formation. Maps were produced for 1965, 1972, 1986, and 2000 from aerial photographs and satellite images. The conversion of tree and shrub cover to cultivation was observed pre-1986; the critical period for gully development in the catchment was 1974–1985. Land cover change thus contributed to gully erosion. An integrated recovery policy is required to restore the catchment to useful productivity.*

***Keywords:*** *Land cover change; Normalized Difference Vegetation Index (NDVI); gully erosion; food insecurity; Ethiopia.*

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## Introduction

Land cover studies examine change in the status of the land surface in order to understand processes and factors regulating change (Kebrom and Hedlund 2000; Reid et al 2000). The results can be used for management planning (Gete and Hurni 2001). Cover can be assessed qualitatively by visual interpretation or quantitatively using spectral reflectance. Change in cover can result from conversion (change from one cover to another) and modification (additions to or subtractions from vegetation). For example, removing forest leads to conversion to cultivated land, while thinning shrubs causes modification. It is important to understand the processes involved in change and how they influence image elements before assessing change (Lillesand and Kiefer 2000).

Change detection by visual interpretation classifies land cover by eye and relates patterns to known ground features (Rembold et al 2000). Aerial photographs reveal features such as grass, trees, and cultivation, but these features are difficult to detect using satellite data (Rembold et al 2000). Satellite data can be used to derive indices for assessing cover change (Dwivedi et al 2005), erosion and sedimentation (Vrieling 2007), and modeling (Saavedra 2005). The Normalized Difference Vegetation Index (NDVI) has been used for time series analysis of vegetation change (Sobrino and Raissouni 2000).

Land cover is important in Ethiopia because it is a primary factor in the regulation of soil degradation. Hurni et al (2005) estimated that cultivated and degraded land generates 10–20 times more runoff than do forests; thus, expanding cultivation can drive soil degradation unless the land is well managed (Morgan 1986).

Umbulo catchment, in Sidama Zone, southern Ethiopia (7°01′N, 38°17′E), suffers from soil degradation and is food insecure (Debub University 2003). This area did not always experience this combination of factors, and better understanding of why change has occurred is limited. Moges and Holden (2007) found that farmers were knowledgeable about soil degradation and later determined that there were few inherent soil fertility issues (Moges and Holden 2008a). Reconstruction of gully development (Moges and Holden 2008b) found that gully erosion was triggered between 1974 and 1985; therefore, the objective of this study was to assess the cover change between 1965 and 2000 in Umbulo catchment and relate it to gully development in the landscape and the trend toward food insecurity.

## Material and methods

Umbulo catchment (Figure 1), in the Ethiopian highlands, is 2565 ha in size. The area was once covered with trees and shrubs, but by 2005 this vegetation was virtually nonexistent (Moges and Holden 2007). Crop residues are used for fuel and animal feed, so cultivated land is exposed between harvesting and crop germination.

For this study, the catchment was divided into 3 landscape sections: (1) steep, degraded, upper-slope


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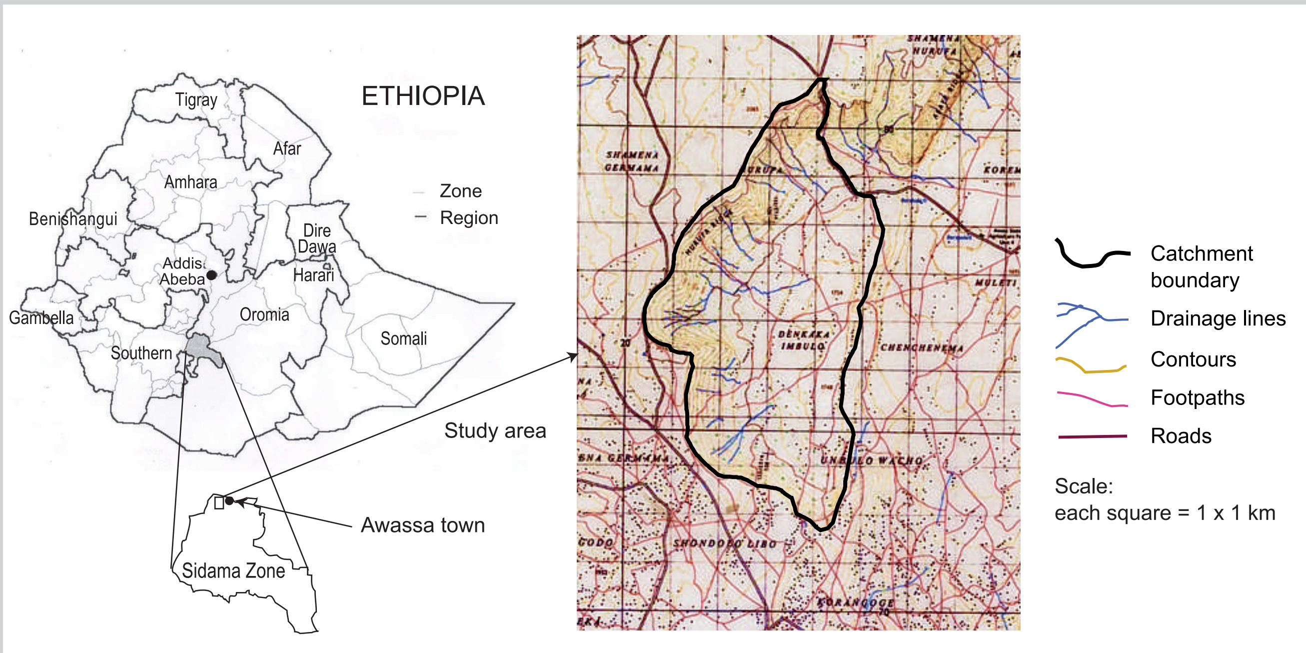
**FIGURE 1** The study area: Umbulo catchment, southern Ethiopia. (Maps by A. Moges)




uncultivated (708 ha, 11–45% slope); (2) gentle-sloping, middle-slope cultivated (698 ha, 8–11% slope); and (3) flat, lower-slope cultivated (1159 ha, <8% slope), delineated by global positioning system survey and using topographic maps. Screen-digitized outlines were used as masks for NDVI analysis from satellite data and as clip themes for aerial photographs. Land cover was determined from aerial photographs (1965 and 1972) and Landsat Thematic Mapper (TM) images (1986 and 2000) and from data collected during the field visits (Moges and Holden 2007, 2008a, 2008b).

The photographs were scanned at 2000 dots per inch and rectified to a 1:50,000 topographic map (EMA 1979). The catchment boundary was delineated using topographic maps and a stereoscope. Land cover types were identified by pattern, shape, size, texture, tone, association, and site (Lillesand and Kiefer 2000) and were screen digitized as shape polygons. The TM images (resolution 28.5 m) were from Landsat 5 (21 January 1986, path 168, row 55) and Enhance Thematic Mapper-Plus (5 February 2000, path 168, row 55). Using Band 3 (visible 0.63–0.69 μm) and Band 4 (near-infrared 0.75–0.90 μm), the images were radiometrically corrected using sensor calibration parameters provided with the satellite images and the formula (Lillesand and Kiefer 2000)

$$L = \frac{L_{\max} - L_{\min}}{255} * DN + L_{\min} \quad (1)$$

where $L$ is the radiance ($Wm^{-2}\ sr^{-1}$) and $DN$ is the digital number, a pixel, and then used to calculate NDVI by

$$NDVI = \frac{\text{Band4} - \text{Band3}}{\text{Band4} + \text{Band3}} \quad (2)$$

NDVI data were analyzed to derive cover classes, which were interpreted by landscape section. Generally, NDVI ranges from −1 to +1, where higher values reflect higher vegetation cover and lower values represent water, snow, and clouds (Lillesand and Kiefer 2000). TM-derived NDVI data were categorized into 5 land cover classes based on the values from literature and field observations. After land cover was classified by landscape section, change was calculated and maps were prepared. IDRISI and ArcView geographic information systems were used for analysis and preparation of the maps.

## Results and discussion

Seven land cover classes were defined from the aerial photographs:

1. *Woodland*—dark color, continuous texture, mainly in the upper section, boundary to shrubland, and along gullies difficult to differentiate;
2. *Shrubland*—differentiated from woodland by type and canopy cover, more open texture compared to woodland, boundary along gullies difficult to differentiate;
3. *Grassland with shrubs*—dominated by grass but containing shrubs, differentiated by shrubs appearing as

dispersed dark spots, grass as lighter color, probably formed by modification of shrubland due to thinning;
4. *Grassland*—grazed area not used for cultivation, light color, smooth texture, no patterning compared to croplands and grassland with shrubs;
5. *Cultivated lands*—land around homesteads, intermixed cover types that cannot be separated, light in color with patterns from plot boundaries;
6. *Vegetation along drainage lines*—along drainage lines, dark color, trees and shrubs, when adjacent to woodland limited to the width of the drainage line; and
7. *Degraded land*—bare surfaces with some grass, color similar to grassland, thus location an important distinguishing factor.

At the whole catchment scale, cover change between 1965 and 1972 (Table 1A; Figure 2) showed increased cultivated land (140%), vegetation along drainage lines (5%), grassland (3.4%), and degraded land (6%) at the expense of woodland and shrubland with grass. There was increased cultivation and a decrease in woody cover that represents the start of removal of vegetation cover from land. The 57 ha $yr^{-1}$ change within this period was much greater than indicated by contemporary reports from northern Ethiopia (Kebrom and Hedlund 2000). To better understand the changes, the catchment was examined using the 3 landscape sections.

In 1965 the steep, degraded, upper-slope uncultivated category was dominated by degraded land, vegetation along drainage lines, grassland, and woodland (Figure 3; Table 1B). Removal of woodland and conversion into shrubland and degraded land occurred by 1972. These changes probably meant that this section started to generate larger amounts of runoff that drained to the lower sections of the catchment. In the gentle-sloping, middle-slope category (Figure 3; Table 1C), woodland and shrubland decreased by 1972. The change in cultivated land from 11 ha to 102 ha (11 ha $yr^{-1}$), at the expense of woodland and shrubland, meant less protection of the land from erosive rains by 1972. In the flat, lower-slope category (Figure 3; Table 1D), woodland and shrubland decreased and grassland with shrubs was completely removed. These cover types converted to cultivated land at a rate of 45 ha $yr^{-1}$. These changes probably decreased the capacity of the land to absorb runoff and allowed rapid flow to the catchment outlet. This is the most likely reason for the formation of a lake, in the late 1980s, near the catchment outflow. A lack of year-round vegetation cover made this section more prone to erosion.

The NDVI ranged from $-0.096$ to 0.562 in 1986 and from $-0.163$ to 0.453 in 2000 and was used to define 5 cover classes. Values for a small lake at the catchment outlet were taken to represent water ($\leq -0.07$), and values between $> -0.07$ and $\leq 0.10$ were interpreted as rock and bare soil (Holben 1986). Mixed bare soil and vegetation ($>0.1$ and $\leq 0.16$, respectively) were determined using the location of remnant-dispersed trees in the catchment. All NDVI values $>0.16$ were classified as vegetation (Sobrino and Raissouni 2000), where $>0.16$ and $\leq 0.45$ was classified as full vegetation and $>0.45$ was classified as high vegetation to account for greater values recorded in 1986 compared to the 2000 maximum value.

At the whole catchment scale, 100% of the lake area was gained and 100% of high vegetation was lost between 1986 and 2000 (Figure 2; Table 2A), and field observations in 2005 confirmed the lake had disappeared. Rock and bare soil as well as mix of soil and vegetation showed very small changes, while full vegetation cover decreased at a rate of $<2$ ha $yr^{-1}$. The steep, degraded, upper-slope section was dominated by the rock and bare soil cover type, which increased by about 5% between 1986 and 2000. The mix of soil and vegetation class and full vegetation class both decreased (Figure 4, Table 2B). The trend of removal of vegetation identified from the aerial photography did not continue to 2000, but was not reversed, either. There was a marked reduction of vegetation cover in the northern parts of the catchment (Figure 4).

An increase in rock and bare soil in the gentle-sloping, middle-slope category (Table 2C) occurred, but NDVI probably represented fields after harvest, and little evidence of widespread soil degradation over this landscape section was found. Most activity was probably confined to the gullies that run across this section (Moges and Holden 2008a). The mix of soil and vegetation class and full vegetation class decreased but represented only 4% of the section area. These mixtures are found in the middle of the catchment (Figure 4), and their placement there could have accelerated soil degradation, as they were serving as a buffer between the steep, degraded, upper-slope and flat, lower-slope sections. On the flat, lower slope, water appeared to have started occupying an area of $>5$ ha (Table 2D). It was reported that a lake emerged late in the 1980s and disappeared around 2002 (Moges and Holden 2008a). The lake (2000) replaced high vegetation (1986) at its location. This occurred because standing water previously accumulated during the rainy season, but the amount of water that remained after the rainy season (June to October) was only sufficient to support vigorous vegetation growth during the dry period (when the satellite image was taken in 1986). As more vegetation was stripped from the upper catchment area, less water was retained and more runoff collected near the outflow, which can persist as a lake through the dry season (seen in 2000).

A direct comparison between 1965/1972 and 1986/2000 cover classes was not possible, so a reclassification was used, as follows: (1) vegetation dominated, characterized by NDVI-derived high vegetation; full vegetation and mix of bare soil and vegetation cover classes; and photograph-derived woodland, shrubland,


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**TABLE 1** Land cover changes between 1965 and 1972 in the whole catchment (A) and in the 3 landscape sections (B–D).

| Land cover type | 1965 | | 1972 | | Change 1965–1972 | |
|---|---|---|---|---|---|---|
| | ha | % | ha | % | ha | % |
| **A. Whole catchment** | | | | | | |
| Woodland | 347 | 13 | 122 | 5 | –225 | –65 |
| Shrubland | 356 | 14 | 201 | 8 | –156 | –44 |
| Vegetation along drainage lines | 192 | 7 | 202 | 8 | 10 | 5 |
| Grassland with shrubs | 173 | 7 | 37 | 1 | –136 | –79 |
| Grassland | 610 | 24 | 631 | 25 | 21 | 3 |
| Cultivated land | 331 | 13 | 784 | 30 | 453 | 137 |
| Degraded land | 555 | 22 | 589 | 23 | 33 | 6 |
| Total | **2564** | **100** | **2566** | **100** | | |
| **B. Steep, degraded, upper-slope section** | | | | | | |
| Woodland | 40 | 6 | 3 | 0 | –37 | –92 |
| Shrubland | 7 | 1 | 25 | 3 | 17 | 240 |
| Vegetation along drainage lines | 118 | 17 | 112 | 16 | –6 | –5 |
| Grassland with shrubs | 1 | 0 | 1 | 0 | 0 | 8 |
| Grassland | 50 | 7 | 52 | 7 | 2 | 5 |
| Cultivated land | 0 | 0 | 5 | 1 | 5 | — |
| Degraded land | 492 | 69 | 510 | 72 | 18 | 4 |
| Total | **708** | **100** | **708** | **100** | | |
| **C. Gentle-sloping, middle-slope section** | | | | | | |
| Woodland | 172 | 25 | 67 | 10 | –105 | –61 |
| Shrubland | 160 | 23 | 125 | 18 | –35 | –22 |
| Vegetation along drainage lines | 73 | 11 | 87 | 13 | 14 | 19 |
| Grassland with shrubs | 31 | 4 | 35 | 5 | 4 | 13 |
| Grassland | 189 | 27 | 210 | 30 | 21 | 11 |
| Cultivated land | 11 | 2 | 102 | 15 | 91 | 823 |
| Degraded land | 61 | 9 | 71 | 10 | 10 | 17 |
| Total | **698** | **100** | **698** | **100** | | |
| **D. Flat, lower-slope section** | | | | | | |
| Woodland | 135 | 12 | 51 | 4 | –84 | –62 |
| Shrubland | 189 | 16 | 51 | 4 | –138 | –73 |
| Vegetation along drainage lines | 1 | 0 | 3 | 0 | 3 | 430 |
| Grassland with shrubs | 141 | 12 | 0 | 0 | –141 | –100 |
| Grassland | 371 | 32 | 368 | 32 | –3 | –1 |
| Cultivated land | 320 | 28 | 678 | 58 | 357 | 112 |
| Degraded land | 3 | 0 | 8 | 1 | 5 | 169 |
| Total | **1160** | **100** | **1160** | **100** | | |

**FIGURE 2** Land cover changes between 1965 and 2000 in Umbulo catchment, southern Ethiopia. (Maps by A. Moges)

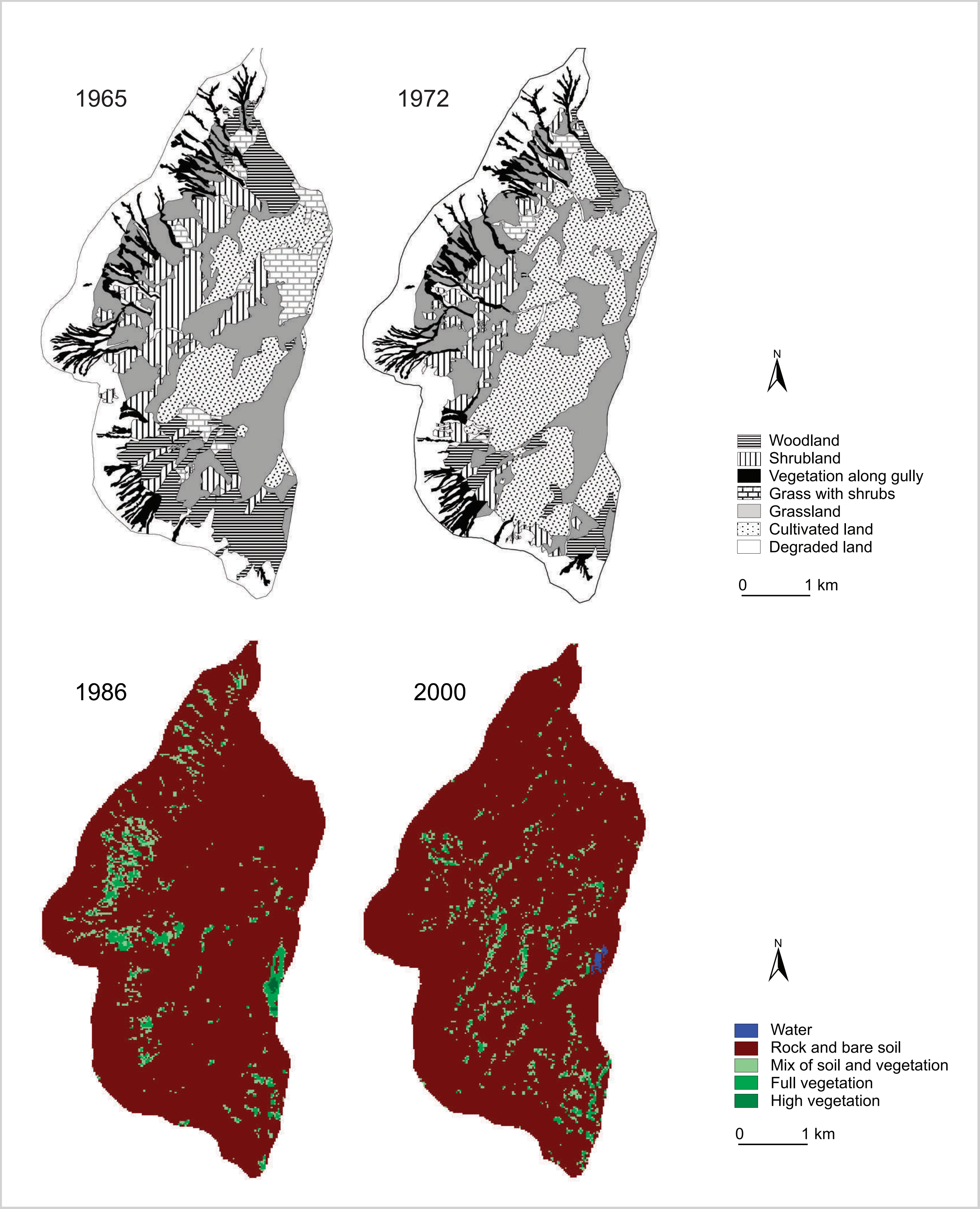
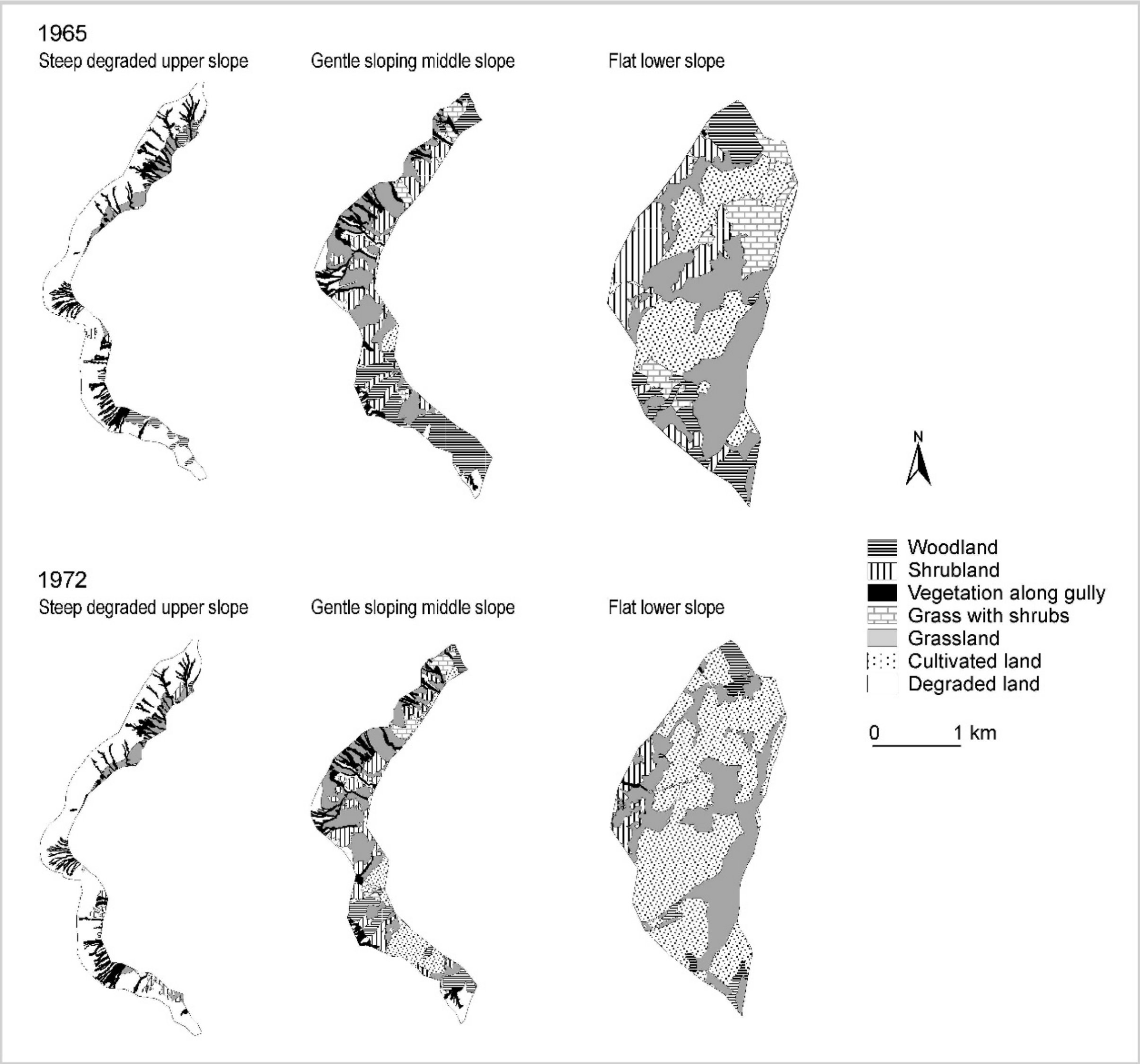


**FIGURE 3** Land cover changes between 1965 and 1972 at landscape level in Umbulo catchment, southern Ethiopia. (Maps by A. Moges)




vegetation along gullies, grassland with shrubs, and grassland classes and (2) exposed-soil dominated, characterized by NDVI-derived rock and bare soil and photograph-derived cultivated land and degraded land classes. All of these cover classes imply that the protection provided to the soil is poor, surface runoff will face little impediment, and the soil is exposed with the onset of rain. Analysis by three landscape sections is presented in Table 3.

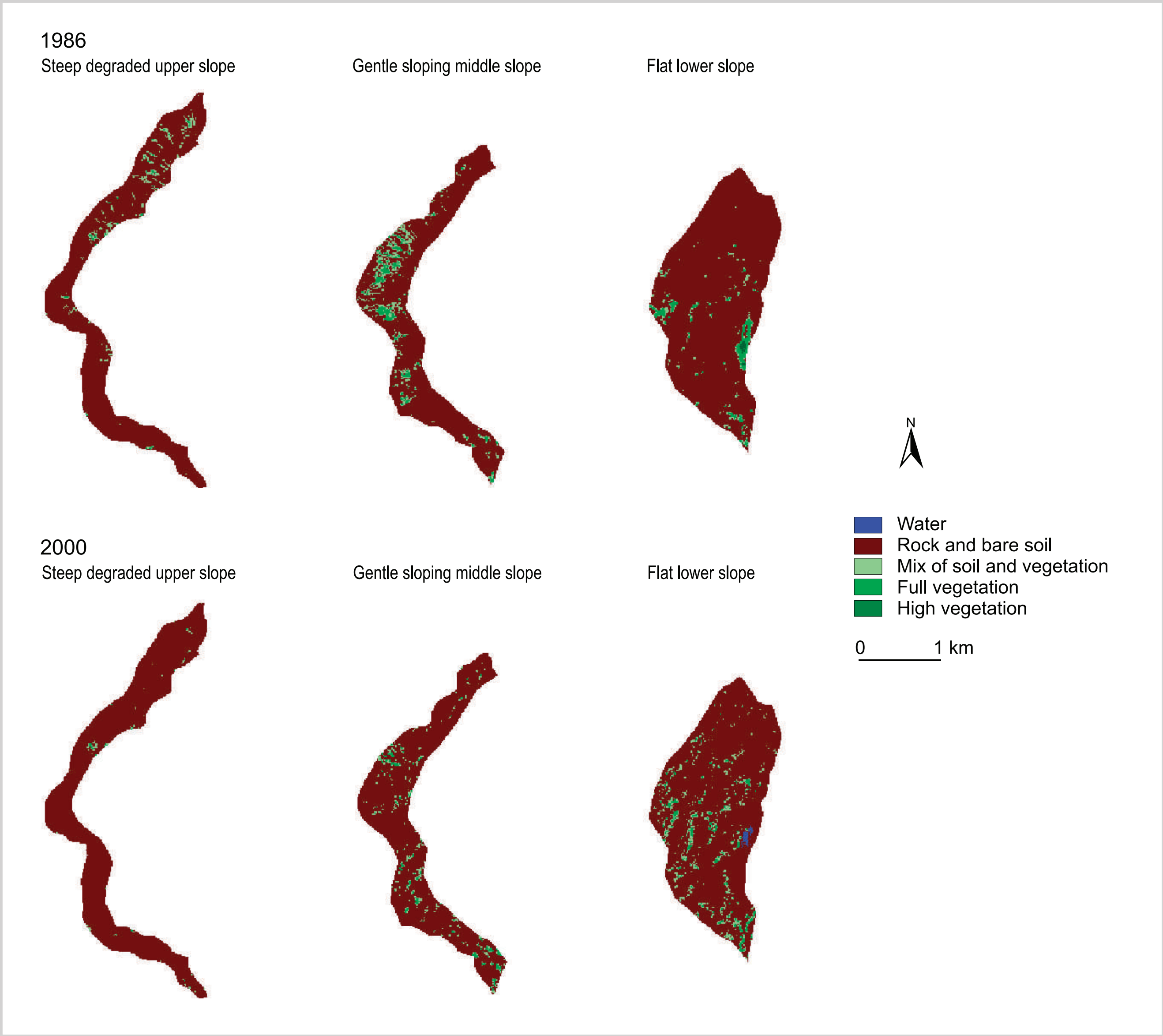
On the steep, degraded, upper-slope section, vegetation-dominated land cover decreased from 31% to 1% by 2000. This can be attributed to increases in cultivation and demand for fuelwood and construction materials associated with population growth. As there was no cultivation in this part of the catchment, the difference represents permanent vegetation loss. Moges and Holden (2007) reported that farmers in the catchment were knowledgeable about the causes of soil degradation and preventative methods, but these data indicate no successful rehabilitation of the area (the primary source of runoff water), either through tree plantation or natural regeneration. Vegetation-dominated cover on the gentle-sloping, middle-slope section decreased from 90% to 8% by 2000. This loss of vegetation cover was crucial to the catchment erosion processes because the lower was previously protected

**TABLE 2** Land cover changes between 1986 and 2000 in the whole catchment (A) and in the 3 landscape sections (B–D).

| Land cover type | 1986 | | 2000 | | Change 1986–2000 | |
|---|---|---|---|---|---|---|
| | ha | % | ha | % | ha | % |
| **A. Whole catchment** | | | | | | |
| Water | 0 | 0 | 5 | 0 | 5 | 100 |
| Rock and bare soil | 2359 | 92 | 2383 | 93 | 25 | 1 |
| Mix of soil and vegetation | 130 | 5 | 125 | 5 | –5 | –4 |
| Vegetation | 73 | 3 | 52 | 2 | –21 | –29 |
| High vegetation | 4 | 0 | 0 | 0 | –4 | –100 |
| Total | **2565** | **100** | **2565** | **100** | | |
| **B. Steep, degraded, upper-slope section** | | | | | | |
| Water | 0 | 0 | 0 | 0 | 0 | — |
| Rock and bare soil | 665 | 94 | 697 | 99 | 32 | 5 |
| Mix of soil and vegetation | 36 | 5 | 7 | 1 | –29 | –80 |
| Vegetation | 6 | 1 | 2 | 0 | –4 | –61 |
| High vegetation | 0 | 0 | 0 | 0 | 0 | — |
| Total | **707** | **100** | **707** | **100** | | |
| **C. Gentle-sloping, middle-slope section** | | | | | | |
| Water | 0 | 0 | 0 | 0 | 0 | — |
| Rock and bare soil | 601 | 86 | 644 | 92 | 43 | 7 |
| Mix of soil and vegetation | 66 | 9 | 38 | 5 | –28 | –42 |
| Vegetation | 33 | 5 | 18 | 3 | –15 | –46 |
| High vegetation | 0 | 0 | 0 | 0 | 0 | — |
| Total | **700** | **100** | **700** | **100** | | |
| **D. Flat, lower-slope section** | | | | | | |
| Water | 0 | 0 | 5 | 0 | 5 | 100 |
| Rock and bare soil | 1093 | 94 | 1042 | 90 | –51 | –5 |
| Mix of soil and vegetation | 28 | 2 | 80 | 7 | 51 | 181 |
| Vegetation | 34 | 3 | 32 | 3 | –2 | –7 |
| High vegetation | 4 | 0 | 0 | 0 | –4 | 100 |
| Total | **1159** | **100** | **1159** | **100** | | |

from runoff generated on the steep, degraded, upper-slope section. Runoff that was once dispersed and utilized by vegetation was channeled to the lower areas of the catchment. Thus, it was probably this loss of vegetation that caused rapid development of the gullies described by Moges and Holden (2008a). The flat, lower slope had fluctuating vegetation cover. In 1965, vegetation cover accounted for 72% of land cover. This decreased to 6% in 1986, but by 2000 it was 10%.

**FIGURE 4** Land cover changes between 1986 and 2000 at landscape level in Umbulo catchment, southern Ethiopia. (Maps by A. Moges)




The recent increase can perhaps be explained by production of *enset* as a garden crop, which is a food security measure, as the crop is resilient in drought conditions. It was confirmed during group discussion (Moges and Holden 2008b) that *enset* was recently introduced to the area. The increase in exposed, soil-dominated land cover can be attributed to expansion of cultivation. The emergence of a lake as well as deposition of low-nutrient erosion sediments (Moges and Holden 2008a) in this section resulted from vegetation changes in the upper catchment sections.

Gete and Hurni (2001) suggest that land cover change studies should consider topography to gain better insight into the process and possible remedial measures. The landscape sectioning approach used in this study, which considered both land use and function, has proved a useful method for understanding change that would not have emerged at the whole catchment scale. Interesting

**TABLE 3** Land cover changes between 1965 and 2000 in the whole catchment (A) and in the 3 landscape sections (B–D).

| Land cover type | 1965 | | 1972 | | 1986 | | 2000 | |
|---|---|---|---|---|---|---|---|---|
| | ha | % | ha | % | ha | % | ha | % |
| **A. Whole catchment** | | | | | | | | |
| Vegetation dominated | 1678 | 65 | 1192 | 46 | 207 | 8 | 177 | 7 |
| Soil exposed | 887 | 35 | 1374 | 54 | 2358 | 92 | 2389 | 93 |
| Total [a] | 2566 | 100 | 2566 | 100 | 2565 | 100 | 2565 | 100 |
| **B. Steep, degraded, upper-slope section** | | | | | | | | |
| Vegetation dominated | 216 | 31 | 193 | 25 | 42 | 6 | 9 | 1 |
| Soil exposed | 492 | 69 | 567 | 75 | 665 | 94 | 697 | 99 |
| Total [a] | 708 | 100 | 761 | 100 | 707 | 100 | 707 | 100 |
| **C. Gentle-sloping, middle-slope section** | | | | | | | | |
| Vegetation dominated | 626 | 90 | 525 | 75 | 99 | 14 | 56 | 8 |
| Soil exposed | 72 | 10 | 173 | 25 | 601 | 86 | 644 | 92 |
| Total [a] | 698 | 100 | 698 | 100 | 700 | 100 | 700 | 100 |
| **D. Flat, lower-slope section** | | | | | | | | |
| Vegetation dominated | 836 | 72 | 474 | 41 | 66 | 6 | 111 | 10 |
| Soil exposed | 323 | 28 | 685 | 59 | 1093 | 94 | 1047 | 90 |
| Total [a] | 1159 | 100 | 1159 | 100 | 1159 | 100 | 1159 | 100 |

[a] The small difference in area calculated by aerial photograph and the satellite image arose because analysis of aerial photographs used vector methods and satellite images used raster methods.

questions arise from the identified cover change: (1) How does this relate to changes elsewhere in the region? (2) Can the gully erosion identified in the catchment (Moges and Holden 2008a) be related to the cover change? (3) Do stakeholders recognize the implications of the cumulative evidence of soil degradation (gully erosion, fertility change, land cover change)?

The general trend of land cover change in Ethiopia is an increase in cultivated land at the expense of woodland and grassland areas (Kebrom and Hedlund 2000; Gete and Hurni 2001). At the national scale, forest decreased from 16% in 1950 to 2.7% by the early 1990s (Million 2001). Similar findings (with some exceptions: Woldeamlak 2002; Solomon 2005) are reported with respect to expansion of cultivation and reduction of forest and grazing lands elsewhere (Table 4). These data, and the data presented here, reveal a critical period of high rate of conversion of land cover to cultivation prior to the 1980s that may have occurred for two reasons: (1) expansion of land area under cultivation by subsistence farming to meet the demands of population change due to growth or migration (Reid et al 2000; Woldeamlak 2002) and (2) change in policies that included land tenure and settlement rights (Reid et al 2000). A change in government in 1974 saw nationalization of land and a redistribution of land to the poor, which also increased cultivated land area.

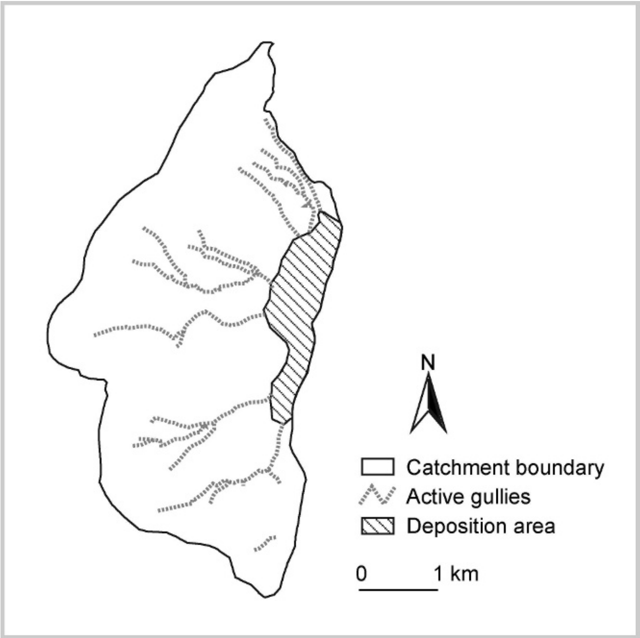
The major erosion type threatening agricultural production in Umbulo catchment is large-scale gullying, shown in Figures 5 and 6 (Moges and Holden 2007, 2008a). Gully development is believed to spread from upslope to downslope, and the rate of soil loss has been estimated to range from 11 to 30 t $ha^{-1}$ $yr^{-1}$ (Moges and Holden 2008a). Moreover, the critical period of gully development was between 1974 and 1985. Gullies were limited to the upper cultivated area during and before 1974, and most of the gullies extended to the middle and lower sections of the catchment by the late 1980s. The development of gullies corresponds to the pattern of removal of the trees and shrubs identified in the catchment. The earlier discussion suggests probable mechanisms for this process.

**TABLE 4** Expansion of cultivated area in northern Ethiopia according to earlier studies.

| Period considered | Rate of conversion (ha/yr) | Area covered (ha), end of period | Rate of change (%) | Study area (ha) | Location | Source |
|---|---|---|---|---|---|---|
| 1957–1982 | 143 | 7150 | 24 | 15,362 | Gojam, northwestern Ethiopia | Solomon (2005) |
| 1982–2001 | –130 | 4683 | –16 | | | |
| 1957–1982 | 109 | 24,832 | 13 | 36,400 | Gojam, northwestern Ethiopia | Woldeamlak (2002) |
| 1982–1998 | –37 | 24,246 | –2 | | | |
| 1957–1982 | 321 | 19,031 | 78 | 27,103 | Gojam, northwestern Ethiopia | Gete and Hurni (2001) |
| 1982–1995 | 143 | 20,893 | 10 | | | |
| 1957–1986 | 2 | 1064 | 7 | 1528 | Wello, North Ethiopia | Belay (2002) |
| 1986–2000 | 1 | 1079 | 1 | | | |
| 1958–1986 | 5 | 5600 | 2 | 11,000 | Wello, North Ethiopia | Kebrom and Hedlund (2000) |

Pressure on the land, lack of water retention, and removal of vegetation in the upper catchment have contributed to frequent crop failure and low productivity, leading to food insecurity. Sufficient action has not been taken by stakeholders, as seen from the dwindling productivity in the catchment. The knowledge and understanding of farmers about the problem and remedial measures (Moges and Holden 2007) can lead nowhere without integrated action by other stakeholders. The nature of gully erosion makes remedial action by individual farmers difficult (Moges and Holden 2008a) and emphasizes the need for attention from regional and national authorities. Monitoring of vegetation change offers a means of assessing the impact of remedial measures in the catchment once a suitable management policy has been developed.

**FIGURE 5** The present active gully network (2006) draining to the outlet at the depositional area. (Map by authors)




## Conclusions

The methodology, which combined different data sources to reconstruct a record of land cover change analyzed by landscape section, should be applicable globally. To understand changes, the catchment had to be split into landscape sections that reflect land use (in this case, mainly farming), topography, and hydraulic function (runoff generation, erosion, and deposition). Evaluation at the whole catchment scale was inappropriate for understanding the link between cover change and soil degradation. Knowledge of the site through field visits was essential for interpretation of both aerial photography and satellite data. Future integration of spatially organized physical and socioeconomic data should improve analysis of cover change data.

Over 35 years, cover change in Umbulo catchment was consistent with observations elsewhere in Ethiopia and Africa, with a trend toward clearing of erosion-resisting vegetation and its replacement by erosive cultivated land.

**FIGURE 6** Typical gully in the gentle-sloping, middle-slope section of the catchment. (Photo by A. Moges)

The methodology enabled a better understanding of how vegetation change influenced gully development. With vegetation cover acting as soil protection (as of 1965), gullies were confined to the badlands, but once removed (between 1972 and 1986), gullies developed over the full catchment area. The farming community and authorities have directly contributed to soil degradation, and rehabilitation will require management of both soil degradation (fertility and erosion issues) and pressure on the land (population pressure, demand for resources). An integrated recovery policy will be required to restore the catchment to useful productivity.

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