8 Landscape Change, Land Degradation, and Sustainable Land Management in the Central Highlands of Eritrea

Thomas Kohler and Hans Hurni

Abstract

This study deals with environmental challenges in the central highlands of Eritrea, a semi-arid region and the most populous part of the country. We use three thematic lenses to focus on landscape change, land degradation, and land rehabilitation. First, we look at deforestation and afforestation since the beginning of the colonial era in 1890; second, we examine soil erosion and soil and water conservation; and third, we consider dam and reservoir construction for the provision of water for domestic use and irrigation. The paper recommends an integrated watershed planning approach to promote regional development and sustainable land management.

Keywords

Land degradation • Landscape change • Soil and water conservation • Sustainable land management • Eritrea highlands

8.1 Introduction

Eritrea, located in the northern part of the Horn of Africa, faces increasing sustainable land management challenges. The country lies along the Red Sea and is bordered by Sudan to the north and west, Djibouti to the southeast, and Ethiopia to the south. Its backbone are its highlands, which extend over the country's central North–South axis at altitudes ranging from 1500 to 3000 m above sea level (Fig. 8.1).

T. Kohler (✉)
Centre for Development of Environment (CDE), University of Bern, Bern, Switzerland
e-mail: thomas.kohler@cde.unibe.ch

H. Hurni
Institute of Geography and Centre for Development and Environment (CDE), University of Bern, Bern, Switzerland

Geomorphologically, the highlands of Eritrea are as diverse as their geology, shaped by tectonic vertical movements and river downcutting leading to the evolution of landforms, the basis on which the more recent development of vegetation and soils, as well as the history of human land use takes place. Much of the Eritrean highlands lies above 2000 m of altitude and comprise extensive areas of structurally horizontal land. This is an expression of the essentially peneplained Precambrian basement rocks covered in part by Tertiary flood basalts (Mohr 1971; Daniel et al. 2009). On a smaller scale, denudational, depositional, and volcanic processes have been significant in shaping the surface of the highlands, while the rivers have incised valleys into the highlands and helped to form relict landscapes (Henricksen et al. 1984).

The highlands include geologic formations of nearly all geologic eras (cf. Kazmin 1973): beginning with Proterozoic deeply weathered and folded metamorphic rocks, Palaeozoic granites and quartz diorites, Mesozoic sediments, Cenozoic plateau basalts, and post-tectonic granites. Tectonic uplifting during the great swell of the Horn of Africa in the second half of the Tertiary intensified fluvial processes due to increased relief energy. Today, the Barka River flows northwards to the Sudanese lowlands and towards the Red Sea, the Mereb River flows westwards into the Sudan lowlands, and a number of rivers along the eastern escarpment flow towards the coastal lowlands, and eventually, the Red Sea, and to the Danakil depression. During the Pleistocene, a series of climate changes, from warm to cold and from wet to dry, propelled soil formation and provided the highlands with their present woody vegetation. In the Holocene, human land users gradually removed the forests, particularly in the highlands, and replaced them with cultivated and grazing land, which resulted in widespread degradation of biodiversity, soil and water.

Covering only one-seventh or 16,750 km^2 of Eritrea's surface, the highlands are home to two-thirds of the country's people—and the population is growing. Most of the

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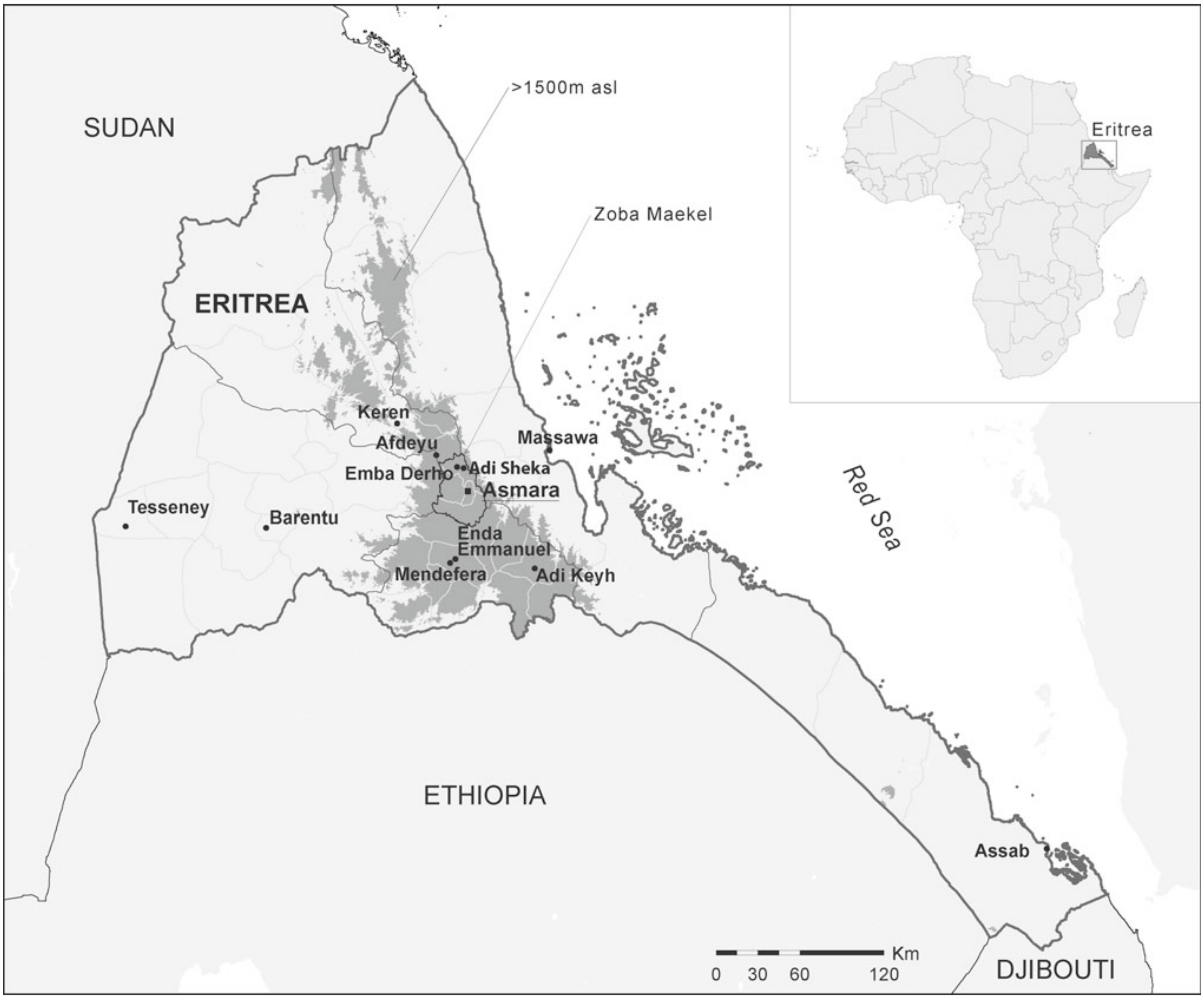

Fig. 8.1 *Map of Eritrea. Highland areas above 1500 m.a.s.l. in dark grey. Map prepared by J. Krauer, CDE University of Bern*

people live in rural areas and derive their livelihoods from small-scale, mixed, rain-fed farming, on farms with about one hectare of cropland per household, combining cereal production—mostly wheat and barley—with livestock keeping (Fig. 8.2). However, annual rainfall is critically low for supporting rain-fed farming. Rainfall records at Asmara meteorological station show an annual average of 509 mm for the period 1914–2015. The main rainy season (June to August) accounts for 76% of the rainfall on average, inter-annual variability is high, and the number of consecutive days without rainfall has been increasing over the last 100 years (Fessehaye et al. 2019). This has led to ever more precarious farming conditions for crop production and to recurrent regional food deficits (FAO 2005). Moreover, with no perennial rivers in the area, the potential for irrigation is limited. And, there is the challenge of soil erosion in what is an area of uninterrupted land use over many generations—probably over many centuries. The highlands are home to the majority of Eritrea's farmers and most of the growing urban population. They include the capital city, Asmara, which is by far the largest urban area in Eritrea and rapidly expanding (Araya and Hergarten 2008). The highlands are also the location of important industrial sites, such as mining enterprises.

The present contribution investigates these challenges with a focus on landscape change, land degradation, and land rehabilitation through three thematic lenses: first, by looking at deforestation and afforestation; second, by examining soil erosion and soil and water conservation; and third, by considering dam/reservoir construction for the provision of water. The geographical focus of this study is Zoba Maekel, the central administrative zone of the highlands (which includes Asmara)—a region also simply known as "the central highlands".

Fig. 8.2 Farmers threshing cereals with oxen, central highlands of Eritrea (photo by Roden 2006)

8.2 Landscape Change: The History of Forest Cover and Current Afforestation Efforts in the Central Highlands of Eritrea

Government policy on land management has been shaped by the belief that forested lands in Eritrea decreased from 30% in 1890 (around the start of Italian colonization) to below 1% in the early 1990s. The figure of 30% has been widely cited in scientific publications, development reports, Eritrean textbooks, and travel guides, laying the foundation for the country's marked efforts in tree planting and afforestation.

The reasons given for this century-long decline in forest cover are the combined effect of destructive land use practices by the Italian colonizers, the war of liberation against Ethiopia, and the unsound land and resource management by the peasantry, i.e. Eritrea's small-scale farmers, including extensive use of wood and timber for cooking and for construction of traditional housing (*Hidmos*). Deforestation is held responsible for a variety of Eritrea's problems, including widespread soil erosion, desertification, lack of surface water, and persistent food insecurity (Liebi 1993; Laett 2004; Boerma 2006). This perception is in line with the narrative of rapid and widespread deforestation in Africa, including Ethiopia and the Greater Horn Area, during the course of a century (McCann 1997; FAO 2001; Boerma 2006). In Eritrea, the image of destroyed forests has served as a metaphor for the oppression and suffering the country had to endure for 100 years starting with colonization. Similarly, it provides a powerful tool for general mobilization for the purpose of national reconstruction. This includes large afforestation campaigns using rural and urban communities and young people during their national service. Forests, thus, symbolize the hope of a green future for all, based on patriotism and nation building. They are seen as a cornerstone to overcoming the country's main environmental problems (Laett 2004; Boerma 2006).

However, research carried out in recent decades casts doubt on the belief that deforestation in Africa is a phenomenon of the recent past—i.e. of the last century. A growing body of evidence suggests that deforestation rates for this period have been largely overestimated, also in the Horn of Africa, and especially in Ethiopia (Wolde-Mariam 1991; McCann 1997; Ritler 2003; Nyssen et al. 2009). There is less research on the history of forest cover in Eritrea, especially relating to the whole country. But for the central highland plateau, there is increasing evidence that forest cover, and hence, forest loss over the last 100 years, has been overestimated (Liebi 1993; Laett 2004; Boerma 2006; Fig. 8.3).

Travel accounts and reports of expeditions in the nineteenth century and early twentieth century all indicate that the Eritrean highland plateau contained very little woodland already then, in contrast especially to the eastern escarpment, which was likely richer in vegetation than today (Matteucci 1880; Munzinger 1890; in Boerma 2006). The Italian colonial administration soon restricted the cutting of trees, restrictions that became increasingly tighter over the years, and very early on began to import timber to meet local

Fig. 8.3 Forest cover and land use at the village of Enda Emmanuel near Mendefera, Eritrean highlands, 1920 (left) and 2004 (right). Both photos show a landscape largely devoid of trees. The 2004 photo shows less open bush on the slope, but more trees in the village, which consists mainly of brick instead of wooden housing (Photos: left: photographer unknown, photo taken around 1920, Istituto Agronomico per l'Oltremare, Firenze. Right: photo by L. Laett, CDE University of Bern, 2004)

construction demands (Martini 1900). A study undertaken by an Italian forestry expert in 1905–07 puts the country's forest cover at about 7% (Senni 1915, in Boerma 2006). A few years later, a second and more detailed study highlighted the stark contrast between the highlands and the eastern escarpment: "While the escarpment is in most places generally wooded the highland plateau instead is completely bare or almost so". The study did not quantify forest cover (Fiori 1913, in Boerma 2006). Recent research based on repeat photography, which compares historical with recent photos, confirms the impression of the highland plateau as an area mostly devoid of trees, suggesting that whatever forest cover there was must have largely disappeared before the Italians arrived around 1890 (Boerma 1999, 2006; Laett 2004). In contrast, on hillsides and steeper slopes, wooded species were often more widespread than today, and olives (*olea africana*) and junipers *(juniperus procera*) have been replaced with acacias in some areas, a change indicating a qualitative deterioration of the woods. To increase tree cover and give the highlands a more hospitable shape, the colonial administration, Italian settlers, and local Eritrean communities engaged in tree planting in the highlands, mostly relying on eucalyptus and sisal. The colonial administration also established eucalyptus plantations in the immediate surroundings of larger settlements and towns, for example in and around Asmara, in Segeneiti and Mendefera (Boerma 1999). On hillsides and steeper slopes, shrub was replaced by *beles (opuntia ficus indica)*. Catholic missionaries reportedly introduced this cactus plant in the early nineteenth century on the eastern escarpment, where it is widespread today. It is also prominent across the highlands, where it forms part of the communal land use system mainly for its fruits (Laett 2004).

From the period of the Ethiopian rule (1952–1991), statistical data on forests and forest cover are largely lacking. Studies carried out by the Ethiopian government in 1974 and later by international agencies (FAO 1984) were hampered by logistical and technical problems at a time of escalating warfare, and their results relating to forest cover appear not to be reliable (Boerma 2006). An extensive reforestation and soil conservation programme was established by the Ethiopian administration, for example along the Massawa-Asmara road on the eastern escarpment. Local communities were incited or coerced to participate in food-for-work programmes, which continued later under the DERG regime after the government of Haile Selassie was overthrown in 1974. By that time, the liberation war was in full rage, but both sides, the Ethiopian and the Eritrean, continued to engage in afforestation and soil and water conservation in the regions under their control. In retrospect, the impact of this 30-year war (1960–1991) on forests is difficult to appraise in quantitative terms. On the one hand, many trees were pillaged and plantations destroyed by the Ethiopian army. Trees were cut to sell in Asmara and other towns and for building trenches by both sides, which consumed a lot of wood. On the other hand, increased inaccessibility of certain areas during the war may have had a positive impact on wood cover in the country. Military activity and mines kept animals and herders away from these often more remote areas. The fall in livestock numbers during the war may also have relieved pressure on vegetation cover, including woods (Boerma 2006).

After liberation in 1991, the new Eritrean government strongly promoted tree planting and other ways of landscape restoration, as it had done already in the years preceding independence. The administration launched massive campaigns to implement terracing combined with afforestation, woodland closures, catchment protection, and dam construction, in an act of faith in future of the country. The high level of resources devoted to afforestation and tree planting has resulted in a remarkable regeneration of much of the highlands in terms of forest cover since the early 1990s (Laett 2004; Boerma 2006). According to the Eritrean Land Use Survey of 2014, tree plantations covered over 16,000 hectares or close to 9% of Zoba Maekel, mostly eucalyptus and some olives (*Olea africana)*. The region ran nine nurseries from which trees were distributed to local communities for planting. Some of these nurseries had been established under Ethiopian rule between 1982 and 1987 (Selamawit and Mihreteab 2016). The region also had 7346 ha (7%) of temporary enclosures, i.e. areas closed for grazing. Such enclosures, based on local traditional practices, have been widely implemented by authorities across the whole highlands to facilitate rehabilitation of degraded overgrazed areas, mainly hillsides, by natural regeneration. Enclosures were often combined with hillside terracing and eucalyptus plantations. Such combined efforts have been used, especially in dam catchment areas, in order to reduce siltation of reservoirs, with a focus on those reservoirs that secure water supply for Asmara (Selamawit and Mihreteab 2016). Farmers' access to the trees they planted is restricted, and grazing in plantations is banned altogether.

The efforts to restore vegetation cover have been complemented over the last two decades by policies to relieve pressure on wood resources. The most prominent example is the promotion of improved cooking stoves (locally called *Adhanet*), mostly through village campaigns. By 2015, over 30,000 stoves, which cut firewood consumption by half, are reported to have been established in Zoba Maekel alone, which is very close to full coverage of all rural households in the Zoba (Selamawit and Mihreteab 2016).

To summarize, there is little written evidence on the extent of forest cover throughout the country in the early days of Italian colonization. For the central highland plateau, neither archival evidence and old travel accounts, nor the results of repeat photography, support the thesis of extensive forest cover in this region around 1890, and an overall, rapid, and general decrease of forest cover since then. If there were ever extensive forests there, they must have disappeared earlier. The story of the highland plateau may well be comparable to that of the landscapes around the Mediterranean Sea. As with the Mediterranean landscapes, the highlands represent an old cultural landscape whose largely sloping land has been tilled and ploughed for centuries, by a dense population largely reliant on wood resources. The loss of forest cover in the highlands is thus very likely to go much further back in history.

8.3 Land Degradation and the Promotion of Soil and Water Conservation

8.3.1 Soil and Water Conservation in the Highlands of Eritrea

Land degradation has negative effects on large tracts of land and renewable natural resources across the world. Drylands are particularly vulnerable, due to unsustainable land management and soil erosion (Schwilch et al. 2012; UNCCD 2014). The highlands of Eritrea present a case in point: erratic, often high-intensity rainfall, scarce natural vegetation, sloping land, and increasing pressure on land resources by a growing population, all contribute to land degradation. Soil erosion has been a key development issue in Ethiopia and Eritrea, well documented since the 1970s and especially since the 1980s (Hurni 1978, 1983, 1987, 1993; Stillhardt et al. 2002; Hurni et al. 2016). In those years, measures against soil erosion were taken by the Ethiopian administration (at that time Eritrea was a province of Ethiopia). After independence in 1993, the Eritrean authorities took up the fight against soil erosion with renewed vigour and widespread action across the country. The 1995 National Environmental Management Plan identified soil erosion as the most important issue relating to natural resource use in the country (Government of Eritrea 1995).

Soil and water are the basis for production in a country where about 80% of the population depend on small-scale, rain-fed farming for their livelihoods. The situation is particularly critical in the highlands. Home to 65% of the country's population, they cover only 16% of the country's territory, and farming is suitable or marginally suitable on only an estimated 30% of the land (Selamawit and Mihreteab 2016). Moreover, mounting pressure on grazing land and wood resources has reduced vegetation cover, especially grass cover, to critical levels in many places. Soil erosion is affecting agricultural production, causing crop yields to decline at an estimated rate of 0.5% per annum (Hurni 1993; Juel 2002). Set against the background of the national production, which covers only about half of the food requirements in a year of adequate rainfall, this is a worrying decline in the long run. Soil erosion is, thus, a threat not only to individual farmers' livelihoods, but also to national food security.

The extent of soil and water conservation measures across the highlands is considerable. While official statistics are hard to come by, satellite imagery can help present an estimate. Automatic classification from highest-resolution satellite imagery (geo-eye), done on a test area of 2330 ha in the central highlands (Eckert et al. 2017), identified different types of overlapping indigenous and introduced conservation structures, typical of the highland areas (Negassi

Fig. 8.4 Extensive soil and water conservation works (terracing) on cropland during a government-led campaign in 1999–2000 near Afdeyu, central highlands of Eritrea (photo by Gurtner 2004)

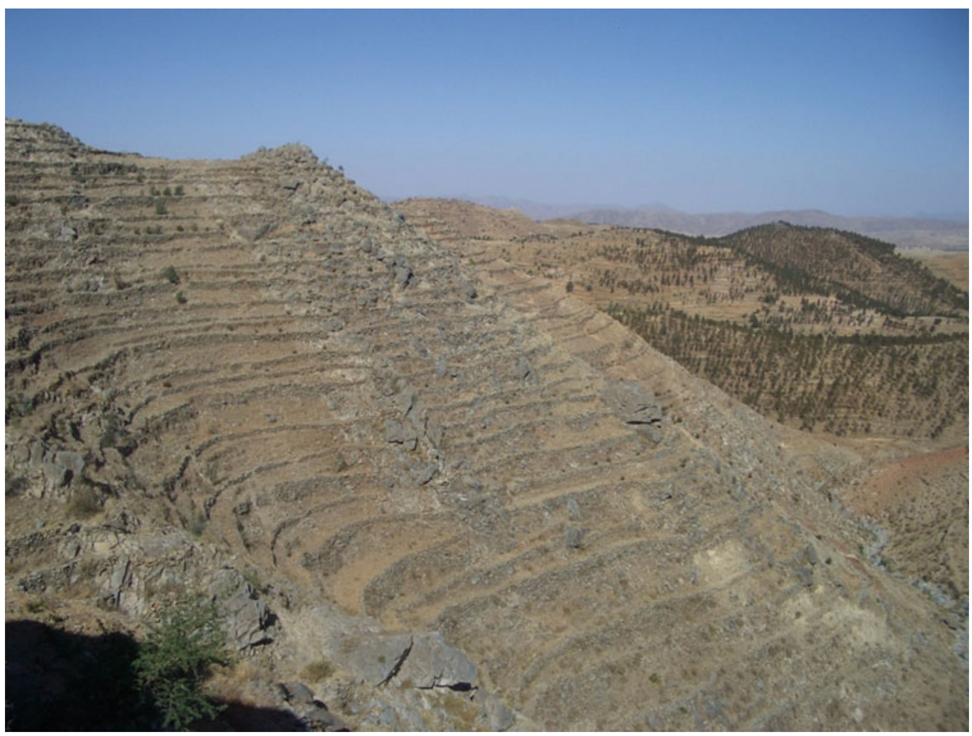

Fig. 8.5 Hillside terracing at Afdeyu in the foreground, with some newly planted eucalyptus on the terraced hills in the background. Previously used for grazing, the hill area was closed off once the terraces were built and the trees planted (photo by Gurtner 2004)

et al. 2002; Ogbazghi et al. 2011). For the entire test area, the analysis found over 1500 km (1,538,370 m) of terraces and bunds on cropland, or about 940 m per ha if 70% of the test area was cultivated, a figure confirmed by ground truthing. According to the Ministry of Agriculture, if we assume that one person built about 8–10 m of terraces or bunds per day, this many conservation structures involved 150,000–190,000 person-days. These figures relate to cropland conservation only (Fig. 8.4), without accounting for the construction of the narrow-based hillside terraces and the tree planting on these (Fig. 8.5). The costs of a comprehensive conservation campaign, including cropland and hillsides, are difficult to establish, but estimates made in 2001 by Denmark's development cooperation agency, Danida, present a figure of about USD 450 per ha (Juel 2002), based on their extensive conservation work with the Ministry of Agriculture across the country. Taking this figure, conserving the cropland of our study area of 2330 ha would have incurred costs of just over USD 1 million, and this for what is but a small fraction of the central highlands (1,042,000 ha). Based on such a small area, this figure might be taken as anecdotal evidence, but it gives an idea of the size of investment needed to protect the soil resources in the area from being washed away.

When soil and water conservation (SWC) activities in the highlands of the Horn of Africa, i.e. in Ethiopia and Eritrea, gained momentum in the late 1970s and in the 1980s, there were no data on erosion rates or on the importance of the factors that defined these rates. Practical measures such as establishing terraces, for example, had to rely on guesswork, or at best, on experiences from other parts of Africa or elsewhere in the world—such as the USA. However, soil erosion is site-specific; while the factors that trigger it can be generalized, their scope and importance vary from one region to the next. Erosion models and conservation work must therefore consider these regional specificities.

To collect the regionalized field-based data required, the Soil Conservation Research Programme (SCRP) was set up in Ethiopia in 1981 (Hurni 1982). Funded mainly by the Swiss Agency for Development and Cooperation, the programme was jointly run by the Ethiopian Ministry of Agriculture and the Institute of Geography, and later, the Centre for Development and Environment, both at the University of Bern, Switzerland. The main objective was to support implementers of soil and water conservation by monitoring soil erosion, testing alternative conservation measures, building local capacity, and informing policy and decision-makers on key aspects of conservation approaches and technologies (Fig. 8.6). The project ran seven field stations, one of which was in the central highlands of Eritrea at Afdeyu, 20 km north of Asmara, at an altitude of 2300 m. Established in 1984, Afdeyu research station remained staffed with records kept through the time of the liberation war. It was handed over to the newly created National Agricultural Research Institute (NARI) of Eritrea in 2006.

Within its research design, Afdeyu had four experimental plots: three for testing different conservation measures and a fourth as the control plot (see Box). The plots were identical in size, slope (31%), and soil properties and represented an average slope angle of the farm (crop) land in the region (Stillhardt et al. 2002). Plot erosion measurements were supplemented with mapping of rill and gully erosion in the catchment area of the station. The station also collected hydrometeorological data, such as temperature, precipitation, evaporation, runoff, and sediment yield of the small watercourse draining the 200 ha-catchment. Key results relating to rainfall, soil erosion, and conservation are presented in Table 8.1 for the years 1989 to 2001. Land use, soil, and conservation mapping in the catchment complemented the experimental work.

The first thing to notice in Table 8.1 is the great inter-annual variability of rainfall (in Asmara, the variation

a b c d

Fig. 8.6 Selection of conservation structures on cropland in the central highlands, from left to right: **a** stone terraces, **b** level bunds, **c** level bunds with tied micro-basins to retain water during rainfall and make it available to crops; **d** effect of SWC on crop growth, here above a stone bund; see text on conservation and crop yields (photos **a, b, d**, by Gurtner 2004; photo **c** by Burtscher 2002)

Table 8.1 Soil loss and runoff for different conservation measures on experimental plots, Afdeyu research station 1989–2001 (Tesfay et al. 2009) *Fanya juu* is a Swahili term meaning "to throw upwards" (i.e. the soil from the trench); the measure was developed in Eastern Africa

Year	Annual rainfall (mm)	Annual soil loss (tonnes per hectare)			
		Control plot	Level bund	Level *fanya juu*	Level double ditch
Mean 1989–2001	480	49.2	11.6	4.6	2.8
Wettest year 1995	658	87.6	21.9	5.5	7.0
Driest year 1990	244	10.4	8.6	1.5	0.4
Year	Annual rainfall (mm)	Annual runoff (mm)			
		Control plot	Level bund	Level *fanya juu*	Level double ditch
Mean 1989–2001	480	222.3	111.4	69.1	57.4
Wettest year 1995	658	248.4	148.4	106.4	108.8
Driest year 1990	244	65.7	90.7	15.7	8.1

coefficient of annual precipitation is 0.32, Billi personal communication). The wettest year received 2.7 times more rainfall than the driest one. Moreover, the annual sequence of precipitation follows no pattern that would allow predictability from one year to the next (Tesfay et al. 2009). Annual totals are low, with three humid months (June–August), and the rest arid (Burtscher 2003, following the classification of Walter et al. 1975). This makes overall conditions for crop production difficult and unpredictable. The data also show that soil erosion was heavy without conservation. On the control plot, on average 49 tonnes of soil/ha were lost per year over the whole period. Soil loss increased to 87 tonnes in the wettest year. The different conservation measures reduced soil loss considerably: for the whole period (1989–2001), annual average soil loss varied between 11 tonnes/ha (level bunds) and as little as 2.8 tonnes/ha (level double ditches). These values correspond to 23 and 6%, respectively, of the loss on the control plot. Assuming a local soil formation rate of 1–4 tonnes/ha per year (Hurni 1983), which would be the maximal tolerable soil loss, two of the three measures tested were thus within these limits and hence appear to be ecologically sustainable. One measure—level bunds—led to soil losses above tolerable levels on average and in the wettest year, but in drier years, also level bunds are close to being sustainable, i.e. in terms of soil formation. Level bunds were the most widespread local conservation practice at Afdeyu and in most parts of the highlands (Fig. 8.6). Farmers prefer them because they require less labour and land compared to other measures.

The soil erosion records at Afdeyu station revealed that a small number of heavy rainfall events (generally storms with over 50 mm in less than one hour) accounted for disproportionally high soil loss. Over the whole recording period (1984–2007), such storms accounted for 15% of all rainfall events and totalled 27% of annual rainfall—but they caused 70% of soil loss (Tesfay et al. 2009).

Experimental plots for testing Soil and Water Conservation (SWC) measures

The plots were 30 m long, 6 m wide, with a slope of 31% and identical soil properties. The following measures were implemented on these plots:

- Plot 1: *Control plot* (untreated)
- Plot 2: *Level bund:* a level embankment 0.3–0.5 m high, made of stones or earth depending on availability of material. Width of bund is 0.5 m. Level means following the contour.
- Plot 3: *Level fanya juu:* a trench dug by throwing the soil upwards to form a level embankment. Over time, the embankment develops into a terrace. *Fanya juu* is a Swahili term meaning "to throw upwards" (i.e. the soil from the trench); the measure was developed in Eastern Africa. Width of trench is 1 m.
- Plot 4: *Level double ditch*: a level embankment with a ditch on the lower and upper side. Ditch height is about 0.5 m, width of each ditch 1.5 m. Level means following the contour.

8.3.2 Soil Conservation and Water Availability

Table 8.1 shows that soil conservation reduces runoff very considerably, particularly during dry years. Without conservation, runoff amounted to 46% of rainfall on average over the whole period. Conservation reduced runoff to 23% (level bunds) and even 12% (double ditches) of total rainfall. In 1990, the driest year in the period, runoff was negligible in *fanya juu* (see box for explanation of this term) and double ditches plots: with over 90% of rainfall retained on the plots with such measures (the control plot retained 74%).

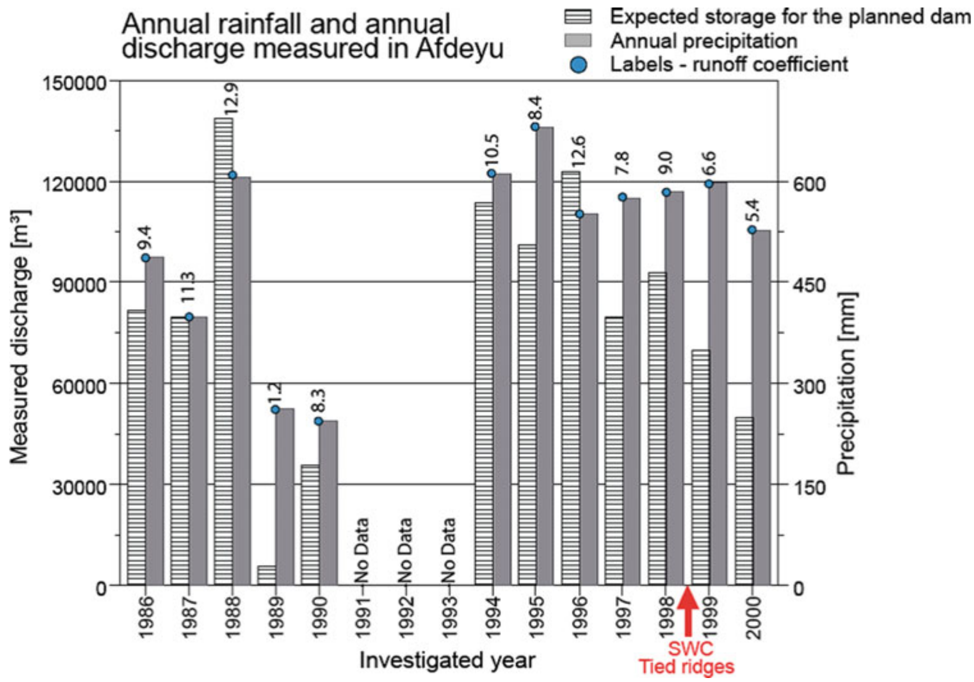

Fig. 8.7 Annual rainfall and river runoff at Afdeyu before and after the 1999–2000 SWC campaign. The Figure shows event (storm)-based rainfall and river discharge (Burtscher 2003)

Conservation measures thus store moisture and make it available for crop production in dry years when it is needed most. This has a positive effect on crop yields, as shown below.

Soil and water conservation had already been carried out in Mayketin Catchment prior to the establishment of Afdeyu research station in 1984. The effectiveness of soil and water conservation was evidenced after a second SWC campaign in 1999 and 2000. The campaign, proposed by the Ministry of Agriculture, was carried out through a cash-for-work programme involving the whole community. It covered the catchment in which the Afdeyu research station was located. Funding came from a programme run by the University of Bern and financed by the Syngenta Foundation for Sustainable Agriculture. The whole catchment (200 ha) was treated at a total cost of USD 60,000—or USD 300 per ha—substantially lower than the Danida figure mentioned above. Yet conservation measures were extensive and included bunds with tied ridging on most of the land to prevent siltation of a small dam planned downstream. After the campaign, runoff from the catchment decreased markedly. The runoff coefficient (percentage of rainfall that flowed off as runoff) was 9–13% before the campaign, dropping to 6.6% after the 1999 campaign, and to 5.4% after completion of the work over the whole catchment in 2000 (Burtscher 2003) (Fig. 8.7). These figures represent the first field-based accounts of the effect of soil conservation on runoff and catchment water yields in Eritrea. They thus provide key data for locating and dimensioning rural dams and reservoirs across the highlands. Such dams are the main source of water for domestic use and irrigation in the central highlands of Eritrea, where river flow is very scarce, ephemeral, or at best seasonal (see Chap. 3 of this book for more details).

The campaign at Afdeyu also led to a higher water table and perennial base flow in the main valley. Prior to the campaign, the flow had dried up in the dry season. The additional groundwater enabled farmers to extend garden irrigation along the valley bottom. The campaign was thus very effective in controlling erosion and improving year-round groundwater availability. Crop yields in the lower section of the plots were higher than in the rest of the plot, most likely due to soil, water, and nutrient accumulation caused by the conservation structures (Stillhardt et al. 2002) (Table 8.2). Improved storage of water in the soil is particularly important, especially if climate trends observed over the last 100 years (no change in total annual rainfall, but higher rainfall intensity and increasing number of consecutive dry days) remain in future. However, farmers were only partly happy because of the loss of arable land due to the relatively space-intensive conservation measures that included micro-basins between the tied ridges. In the years after the campaign, many farmers ploughed these basins over to reclaim land for cultivation.

8.3.3 Local Traditional or External International? Merits and Demerits of Different Conservation Approaches

Farmers are well aware of the threat of soil erosion and of the importance of soil and water conservation. A study in a central highland community documented over 20 traditional

Table 8.2 Average crop yields (medians, in g/m^2) on terraced land (soil and stone bunds) for the period 1984–1998 (Stillhardt et al. 2002)

Position of yield samples	Barley	Wheat	Potato	Onion	Linseed	Maize
Above lower bunds	206	148	3913	933	37	738
Between bunds	198	112	2638	1571	33	368
Below upper bunds	183	124	2601	1735	30	375
Number of yield samples	44	31	11	8	11	3

Table 8.3 General characteristics of local traditional and external international soil and water conservation approaches, Eritrea

Characteristics	Local traditional SWC approach	External international SWC approach
Designed by	Farmers (local)	Engineers, development planners (national, international)
Purpose	Maintain and enhance farm production, especially relating to crops	Maintain regional resource base (soil and water) and ecosystem services
Level of integration	Farm operations at household level	Catchment, watershed
Design	Modifiable; site and household-specific. Structures take up a minimum of land	Standardized design. Structures may take up much land
Area of application	Cropland (plots) of individual household	Whole catchment: uncultivated hillsides, communal grazing land, and cropland
Approach	Individual household initiative, farmer-to-farmer exchange; no external support	External initiative; campaign, often by FFW/CFW, external technical support
Implementation	Incremental and individual, fitting into household labour availability	One-time, collective campaign
Labour requirement	Variable and preferably low	High to very high
Inputs / costs	Low, if any, external material input	Generally high; involves external input
Returns	Benefits go to individual farm	Benefits go to local community and to downstream and external users
Documentation	Practices and effects poorly documented, but handed down locally	Substantial body of research and implementation experience

FFW Food-for-Work, *CFW* Cash-for-Work (Gurtner et al. 2006, modified by authors)

conservation measures still in local common practice (Gurtner et al. 2006). Such practices typically focus on securing food production and hence on cropland (Table 8.3). To keep labour investment low, conservation work is done when household labour is available, and integrated into other fieldwork as a side activity. Land ownership in the highlands is vested in the village community and reallocated among its households at regular intervals, generally spanning seven-year cycles. Farmers were clear that this tenure regime does not provide sufficient incentive for heavy investment in conservation. Given that land holdings are generally around one hectare per household, conservation measures are chosen to occupy as little of the scarce cropland as possible.

In comparison, external approaches, following the international mainstream, often require much more land and labour. If the labour is paid, for example through cash-for-work or food-for-work, such approaches are also extremely expensive. Conserving one square kilometre of land by standard measures such as those applied in government campaigns in Eritrea would then cost about USD 45,000, as mentioned earlier (Juel 2002). However, external approaches have their merits, too. Normally, they are regionally inclusive as they treat entire watersheds or catchments, thus addressing erosion comprehensively in terms of space. After all, cropland is only one source of erosion and not necessarily the most important one. Especially in Eritrea: in the central highlands, for example, grazing lands including steep hillsides accounts for over 60% of the land (Selamawit and Mihreteab 2016). In contrast to traditional measures, their focus in safeguarding critical ecosystem services extends beyond the local scale and thus supports regional development. One example is securing the provision of water for urban development by preventing siltation of local reservoirs.

Future efforts in soil and water conservation should be integrated into collaborative watershed management and regional planning, particularly in the central highlands of Eritrea with their increasing demand for land and water for

Fig. 8.8 Dam with reservoir and gauging station, central highlands of Eritrea. In the background, the village of Emba Derho (photo by S. Tesfay)

Table 8.4 Dams and reservoirs in the central highlands of Eritrea (Zoba Maekel) 1890–2007 (Daniel et al 2009)

Year of construction	Total number of dams	Total design capacity (m^3)	Mean design capacity (m^3)	Main water use	Number of dams with local irrigation	Irrigation (ha per dam)
1890–1951	8	7,110,000	888,800	Urban	4	4–5 ha
1952–1991	32	36,043,000	1,126,300	Urban and rural	19	2–33 ha
1992–2007*	23	21,220,000	922,600	Urban and rural	9	2–29 ha
2008–2015**	18	No data	No data	Urban and rural	No data	No data
Total	81	No data	No data	Urban and rural	No data	No data

According to Eritrean classification, dams have a designed reservoir capacity of $\geq$ 70,000 m^3
* 1992–2007: *Source* Daniel et al. (2009)
** 2008–2015: *Source* Selamawit and Mihreteab (2016)
Note Main water use: *Urban*: domestic, services, and industry, mainly for the capital, Asmara. *Rural:* livestock, watering and small-scale, village-based irrigation

farming, industry, services, and domestic use. Collaborative management will need flexible approaches, in order to better reconcile local farmers' needs with regional development agendas (Table 8.3).

8.3.4 Dam Construction and Sustainable Land Management

The central highlands have no perennial watercourses and ground water availability is limited, owing to the rocky underground of the area (mainly a lateritic crust covering the planation surface of the basement rocks in the Asmara plateau—see Chap. 1 of this book for more details). The region's water supply thus critically hinges on dam construction and rainwater stored in their reservoirs (Fig. 8.8). The central highland zone (Zoba Maekel, 1042 km^2) had 125 artificial reservoirs in 2015, thereof 81 dams, i.e. reservoirs with a storage capacity of 70,000 m^3 or above in accordance with the classification applied in Eritrea; see Selamawit and Mihreteab (2016), and (Table 8.4). Storage capacity varied greatly; while most dams had between 70,000 and several hundred thousand m^3, the few largest ones were designed to store several million m^3 and the

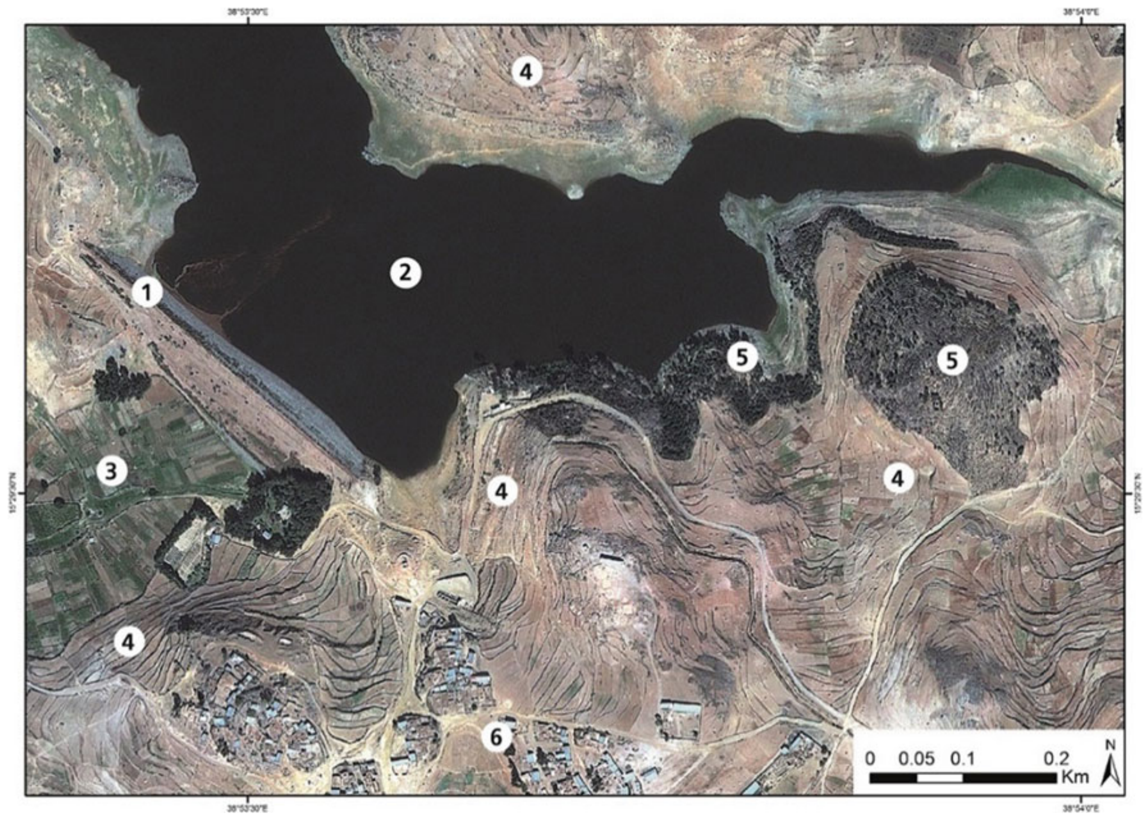

Fig. 8.9 This satellite picture shows the key elements of landscape change in the central highlands of Eritrea as described in this paper. Following the numbers on the picture, we can identify a dam **(1)** and reservoir **(2)** (in this case the dam of Adi Sheka, constructed before 1930 by the Italian colonial administration). The dam, its water body, and garden irrigation **(3)** are new features of the regional landscape and new to Eritrean small-scale farming. Terracing on cropland **(4)** and on hillsides together with afforestation **(5)** aim to prevent soil erosion and siltation of the reservoir. Village areas are indicated by **(6)** (*Source* Geoeye-1 subset acquired in December 2013 showing a true colour RGB image. Image © 2013 DigitalGlobe, Inc. All Rights Reserved. Numbers (1–6) on image inserted by S. Eckert and S. Kummer, CDE University of Bern, 2020)

largest reservoir, built to supply water to Asmara, was designed to hold 26 million m^3 (Daniel et al. 2009).

The first few dams were constructed in colonial times by the Italian administration, mainly to secure the water supply of Asmara, and are located near the town. Dam construction continued during Ethiopian times between 1952 and 1991, especially in the 1980s, when Ethiopia attempted a leap forward in Eritrea in its failed Red Star military campaign. Dams in this decade were funded by the international donor and aid community. This support came in response to the devastating famine in Northern Ethiopia 1983–85, which also affected Eritrea. Generally, activities followed a sustainable land management approach, including soil conservation, afforestation, and area closures in the catchment area of the dams.

The main aim of dam construction in this period was to supply water to rural areas, including small-scale irrigation for village communities, to improve food production and local livelihoods. Construction was done in food-for-work campaigns (Hurni 1985). In Zoba Maekel, the irrigation areas are mostly located in the valley bottoms below the reservoirs. They are small, rarely exceeding 10 ha (Table 8.4), but could be more than doubled if managed more effectively. This would mean reducing present conveyance losses due to unlined furrows, and improving irrigation schedules, i.e. abandoning untimely or excessive irrigation (Daniel et al. 2009).

Dam construction intensified after independence, not only in Zoba Maekel with more reservoirs created on an annual basis than before (Table 8.4), but also elsewhere in the highlands and especially in the western lowlands, in a bid to increase national food security. Across history, the majority of the dams (more than 40 out of the total of 81) were built by government bodies, mostly the Ministry of Agriculture, nine by the Italian colonial administration, and the rest by various civil society organizations including institutions close to the Catholic and Protestant Churches (Daniel et al. 2009). Estimates show that all 81 dams are designed to store as much as 70% of the runoff from their catchment. As rainfall is given, and in the perspective of a decreasing annual precipitation trend (see Chap. 2 of this book for more details), the potential for construction of additional reservoirs in Zoba Maekel is limited, especially if soil conservation in the catchments is intensified and hence runoff reduced. The figure of 70% storage refers to design capacity, meaning that reservoir siltation is not considered. Siltation is a problem, but reliable data on its magnitude are not available. Estimates from a rudimentary bathymetric survey in nine reservoirs established an average cumulative siltation rate of 23%, reporting two dams constructed in the 1930s and 1940s as completely silted up and one dam as broken (Daniel et al. 2009). Siltation of the 81 dams in service in the study area may vary greatly from one reservoir to the other, depending on reservoir age, nature of catchment, and amount and effectiveness of conservation work done therein.

8.4 Concluding Remarks

The Eritrean highlands—especially the central highlands, with their rapidly growing rural and urban population—are key to the future development of Eritrea. But natural limitations are significant, with a critically low level of annual rainfall for rain-fed farming and high inter-annual variations. The effects of climate change on farming are palpable, with an increase in the number of consecutive dry days as well as in rainfall intensity, over the last 100 years. With no perennial rivers or substantial groundwater resources in the area, most of the water supply is provided by rainfall stored in reservoirs. Soils have been worked for many generations and over many centuries, and soil degradation is widespread. Wood resources for fuel and construction are scarce.

However, not all is doom and gloom. Forest cover has increased considerably over the last decades, thanks to successive afforestation campaigns. What needs rethinking is the exclusive use of eucalyptus trees. Considering mixed stands including indigenous trees would reduce the threats associated with monocultures and increase biodiversity. In terms of combatting soil erosion, much has been achieved in soil and water conservation since the 1980s. Overall, afforestation, soil conservation works, and dams with their reservoirs are new physical features of the central highlands; they have led to a remarkable change in the regional landscape over the last 100 years and have increased its diversity (Fig. 8.9).

For future works, a watershed approach could help reconcile the needs of rural with those of urban areas and balance the interests of upstream with downstream users. Structures should be optimized to protect soils while occupying as little of the scarce cropland as possible and allow enough runoff to enter streams to fill the reservoirs that secure regional water supply. Irrigation, a relatively new form of land use for most farming communities, could be substantially expanded by water-saving conveyance and more effective irrigation schedules—a task for agricultural extension. These are but a few examples that could help lead the way to a sustainable future of land management. Urban areas and small central places have an important function too, as they provide services and employment for a growing rural population running short of land. A regional masterplan for sustainable land and resource management could provide the necessary guidance on how to coordinate such initiatives and others.

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