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Desertification? Northern Ethiopia re-photographed after 140 years

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ABSTRACT

A collection of sepia photographs, taken during Great Britain's military expedition to Abyssinia in 1868, are the oldest landscape photographs from northern Ethiopia, and have been used to compare the status of vegetation and land management 140 years ago with that of contemporary times. Thirteen repeat landscape photographs, taken during the dry seasons of 1868 and 2008, were analyzed for various environmental indicators and show a significant improvement of vegetation cover. New eucalypt woodlands, introduced since the 1950s are visible and have provided a valuable alternative for house construction and fuel-wood, but more importantly there has also been locally important natural regeneration of indigenous trees and shrubs. The situation in respect to soil and water conservation measures in farmlands has also improved. According to both historical information and measured climatic data, rainfall conditions around 1868 and in the late 19th century were similar to those of the late 20th/early 21st century. Furthermore, despite a ten-fold increase in population density, land rehabilitation has been accomplished over extensive areas by large-scale implementation of reforestation and terracing activities, especially in the last two decades. In some cases repeat photography shows however that riparian vegetation has been washed away. This is related to river widening in recent degradation periods, particularly in the 1970s–1980s. More recently, riverbeds have become stabilized, and indicate a decreased runoff response. Environmental recovery programmes could not heal all scars, but this study shows that overall there has been a remarkable recovery of vegetation and also improved soil protection over the last 140 years, thereby invalidating hypotheses of the irreversibility of land degradation in semi-arid areas. In a highly degraded environment with high pressure on the land, rural communities were left with no alternative but to improve land husbandry: in northern Ethiopia such interventions have been demonstrably successful.

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1. Introduction

In a bid to force Great Britain to conclude an alliance against Turkey, Ethiopian emperor Tewodros imprisoned a group of Britons and other foreigners in the mid-1860s (Rubenson, 1978). In 1867, an election year in Great Britain, political expediency and public sentiment forced a military action to "free the hostages". The resultant "Abyssinian Expedition" took the British army 650 km from the Red Sea coast to the Ethiopian monarch's mountain citadel at Maqdala. Photographs taken by the 10th Company, Royal Engineers, constitute the earliest landscape photographs of Ethiopia (Pankhurst and Gérard, 1996).

A common perception of a far more luxuriant forest and vegetation cover in the northern highlands of Ethiopia a hundred years or more ago, has been challenged on the basis of historical and stratigraphic evidence (Pankhurst, 1995; Ritler, 2003; Wøien, 1995). We have examined 140 year-old photographic material from northern Ethiopia and compared it to current landscapes, and also used the photographic coverage to assess the impact of land rehabilitation programmes. As modern population growth is assumed to have accelerated land degradation, on account of a progressive change in land use with the main purpose of increasing food production within subsistence farming systems (Wøien, 1995), huge efforts have been undertaken in northern Ethiopia at a regional scale (10^5 km^2) to control soil erosion — for instance through the construction of stone bunds and the rehabilitation of steep slopes (Descheemaeker et al., 2006a,b; Nyssen et al., 2007a).

2. Materials and methods

2.1. *Study area*

The study area lies on the western shoulder of the Rift Valley in the north of Ethiopia between 11° and 14° N, extending over an area of some 10^4 km^2 (Fig. 1). Major lithologies are Mesozoic sandstone and limestone and Tertiary basalt. Erosion, in response to the Miocene and Plio–Pleistocene tectonic uplifts (order of 2500 m), resulted in the formation of tabular, stepped landforms (between 2000 and 2800 m a.s.l.), reflecting the subhorizontal geological structure (Beyth, 1972; Kieffer et al., 2004). Intervening mountain ranges rise locally to 3500 m a.s.l. These high elevations result in a more temperate climate than would normally be associated with the latitude (Virgo and Munro, 1978). Average yearly rainfall ranges between 500 and

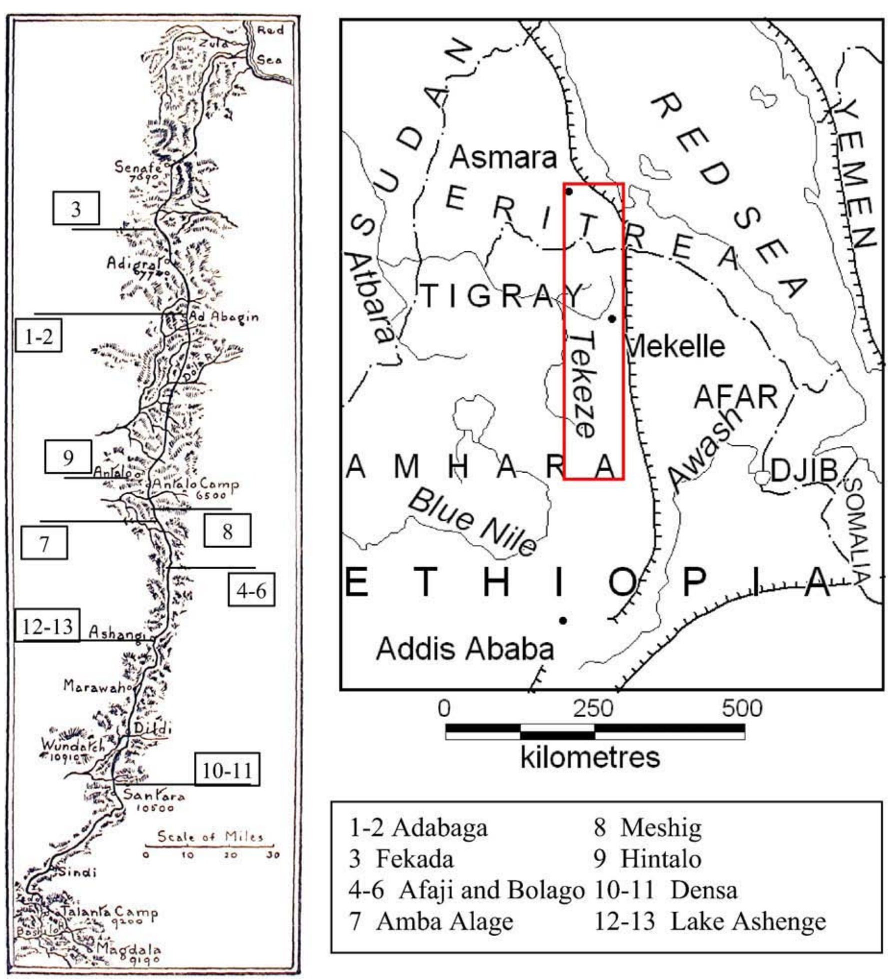

Fig. 1 – Location of the studied sites. Detailed map of the Abyssinian expedition after Cowper (1939).

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900 mm yr^{-1}, with a unimodal pattern, except in the southern part of the study area where a second (smaller) rainy season locally allows growing two successive crops within one year (Nyssen et al., 2005; Rosell and Holmer, 2007).

Analyses of time series of annual precipitation, reaching up to 2000 CE, both for Addis Ababa and the northern highlands, show that although the succession of dry years between the late 1970s and late 1980s produced the driest decade of the previous century in the Ethiopian highlands, there is no evidence for a long-term trend or change in the region's annual rain regime (Conway, 2000; Nyssen et al., 2005). Neither was 1868 a particular year of drought, or of epidemics or famine (Pankhurst, 1985).

The dominant land use is small-scale rainfed subsistence agriculture, for which the main constraints are inadequate soil water and excessive soil erosion (Virgo and Munro, 1978). In the nineteenth century the land use system was similar to the current, though the photographs show generally that through time the cultivated and forest/woodlot domains have been extended at the expense of rangeland. Since the 1980s a land tenure regime has been introduced leading to an approximate equalization in size of landholdings between households: according to Hendrie (1999) "there is no single household or other kind of social group capable of concentrating land in large amounts".

The size of total population of Ethiopia (current boundaries) in 1868 was interpolated at 6.6 million from estimates dating back till 1820 and census results starting from the 1950s (Maddison, 2006; McEvedy and Jones, 1978), against approximately 77 million actually. More precise data or estimates for the study area are not available. Obtained low population numbers in 1868 are corroborated by the small amount of houses visible on most photographs.

Besides famines and droughts over the last 140 years, the Ethiopian environment has also undergone several shocks related to internal and international wars (Stahl, 1990).

2.2. *Repeat photography*

This study has combined findings of more than 10 years of fieldwork with the repeat photography methodology, which has been used for landscape studies (Boerma, 2006; Griffiths et al., 2004; Grove and Rackham, 2001; Hall, 2001; Munro et al., 2008; Nievergelt, 1998; Rohde and Hilhorst, 2001; Turner et al., 1998) covering up to 100 years of change. As the name implies, repeat photography means retaking photographs from the same spot and of the same subject several times; it requires precise repositioning of the camera and composition of the subject (Hall, 2001), which in our case meant rephotographing a distant landscape.

Landscape photographs of north Ethiopia, taken during the "Abyssinia expedition" in 1868 (Gordenker and Cohen, 2006) have been obtained. Thirteen landscapes photographed in early 1868 (dry season) have been revisited in the same season in 2008 and a new set of photographs prepared. They cover a north–south transect between the Red Sea coast and Maqdala (Fig. 1) and provide a fair representation of the 1868 landscape. It can be assumed that the location of the interpreted landscapes is random, insofar that the photographers could not foresee environmental changes that would take place in these areas.

The relocation of the historical photographs was based on rough indications on some of the photographs, detailed scrutiny of maps of the route of the "Abyssinian expedition" (obtained from the Kings Own Museum at Lancaster; http://www.kingsownmuseum.plus.com/contact.htm), knowledge of landscape forms induced by various lithologies, and a dozen-year long geomorphological research experience in the study area. The camera position was furthermore obtained by identification of unique landscape features such as mountain peaks, drainage ways, and their relative position. Finally, the exact camera position and orientation were then obtained by lining up near and distant objects in a triangulation system. Not all photographs could however be repeated; particular problems concerned the absence of identifiable objects.

The 1868 photographs were made with a Dallmeyer's triplet achromatic camera (Gordenker and Cohen, 2006) and the 2008 with a digital Panasonic© DMC-LS65 camera.

2.3. *Expert rating*

For this study, the photographs were shown to eight scientists who have longstanding research experience on geomorphology and land management in Ethiopia and elsewhere. Only photo-couples, taken at exactly the same place, in the same season and under the same angle were considered. The immediate foreground is dependent on the exact position of the photographer. To avoid bias, it was masked for the analysis, unless it had clear reference points. The full dataset of time-lapsed photographs is presented as online Supplementary Data.

The photo-monitoring analysis involved comparing on-the-ground conditions of 2008 (presented as black and white photographs) to photographs depicting the 1868 conditions, whereby scores were assigned by the experts.

For every couple of time-lapsed photographs, the experts interpreted various indicators (Table 1), for which they compared both photographs.

The evaluation was then converted into numerical scores:

−2: the situation has strongly deteriorated,
−1: deteriorated,
0: unchanged situation,
1: improved,
2: the situation has strongly improved.

Given that the scoring method used ordinal variables, the median score per indicator was calculated for every photo-couple, provided that at least four of the eight experts thought the indicator relevant for the photo-couple. Averages of the median scores were then calculated for each indicator, for the whole set of time-lapsed photographs. The deviation of the averages from zero (no change) was tested with the Wilcoxon signed-rank test (Diem, 1963). In a situation whereby many landscapes showed either deterioration, or strong improvement of woody vegetation cover, with few or no observations that matched the calculated average, the ratings for several indicators were not normally distributed; hence a non-parametric statistical hypothesis test was used. The results of these ratings were linked to findings of more than ten years of field research (Descheemaeker et al., 2006a,b; Nyssen et al., 2006, 2007a, 2008). This combination of methods allowed for a holistic analysis of

Table 1 – Interpretation of landscape change in the study area between 1868 and 2008 (n = 13)

Visible soil erosion indicators	n	Score	Change
Woody vegetation	13	1.2 *	Improved
Woody vegetation except eucalyptus	13	0.3 ns	Slightly improved
Visible soil erosion	12	0.1 ns	
Soil and water conservation	12	0.7 *	Improved
Land management	13	1.0 *	Improved

n = number of landscape sites where the phenomenon was observed by at least 4 of the 8 experts; score = average of the median scores given to all the interpreted landscapes, ranging from −2 (strong deterioration) to +2 (strong improvement), with level of significance for the deviation from a test value zero (no change) (* significant at 0.05 level; ns not significant); change = comparison of the situation in 2008 with that in 1868.

observed landscape changes incorporating details on vegetation cover and soil erosion in this marginal semi-arid area.

3. Results and discussion

3.1. *Remarkable changes in 140 years*

In the study area land management and vegetation cover (Fig. 2) have improved (Table 1). The situation in regard to physical conservation measures in farmland has also ameliorated (Fig. 3). A similar study covering a more recent period (Munro et al., 2008) shows that, both at landscape and land unit scales, the situation for natural resources has improved (and in some areas greatly improved) since 1975. The evidence indicates that recovery took place essentially, if not exclusively in the most recent decades.

The average scores (Table 1) hide the degree of variation that exists between sites in their response to environmental change over the last 140 years. At eleven of the thirteen sites, tree cover has increased. In Bolago (Fig. 2) it has greatly improved, but some extreme cases of land degradation also exist. These are related to river widening (Fig. 4) or removal of indigenous vegetation (Fig. 3), the effect of which could not be countered by widespread introduction of eucalypts. Overall, land management was found to have improved in 11 of the 13 analyzed landscapes.

3.2. *Environmental recovery programmes*

The population of Ethiopia within its current boundaries has increased from approximately 6.6 million (Maddison, 2006; McEvedy and Jones, 1978) to 77 million between 1868 and 2008. Furthermore, analyses of time series of annual precipitation, from 1900 to 2000 CE, for both Addis Ababa and the northern highlands (Conway, 2000; Nyssen et al., 2005), show that although the succession of dry years between the late 1970s and late 1980s were the driest decade of the last century in the Ethiopian highlands, there is no evidence of a long-term trend or change in the region's annual rainfall. The land rehabilitation that has taken place, despite strongly increased population density, becomes comprehensible when one considers the large-scale implementation of land management activities. Environmental recovery programmes were initiated by the government in the early 1980s, with collective terracing and reforestation activities later initiated in the then rebel-controlled areas of Tigray

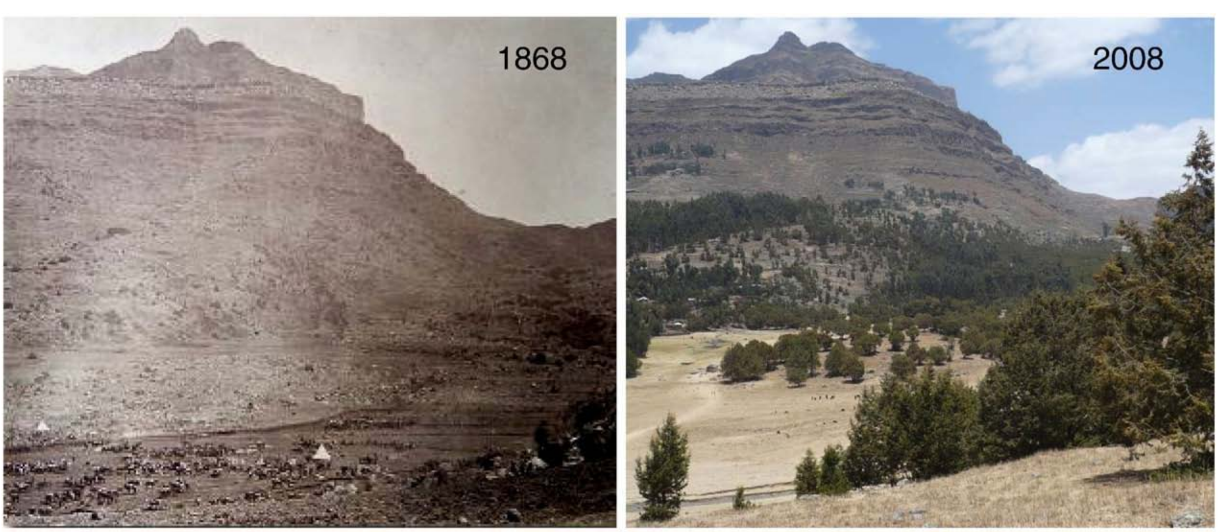

Fig. 2 – Eight experienced geomorphologists and soil scientists have evaluated and rated all repeated photographs in black and white print. At Bolago, tree cover has much improved since 1868. A gully in the foreground of the 2008 photograph was created before afforestation started in the late 1980s.

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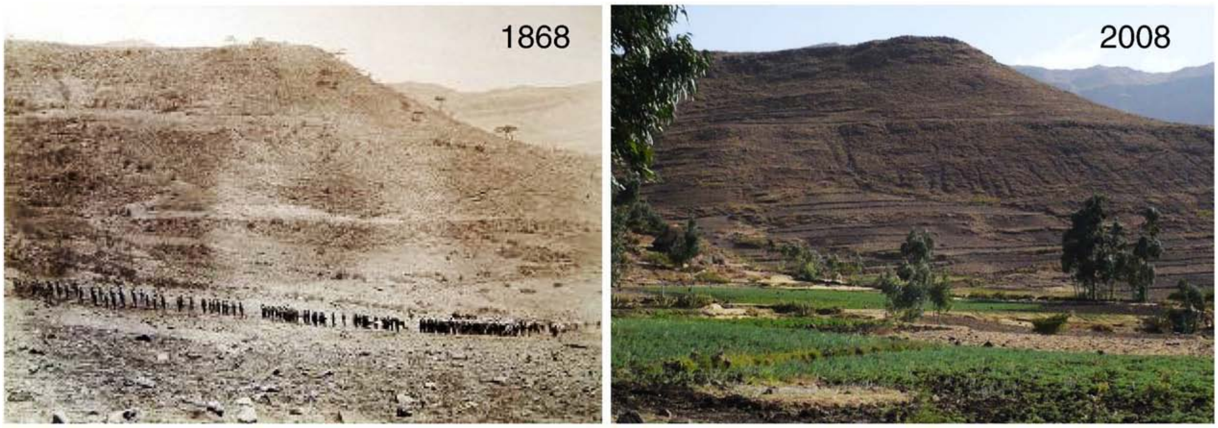

Fig. 3 – Escarpment of the Wadela plateau. Compared to 1868, human occupation has strongly increased. Eucalypts have been planted around houses and farmland expanded, and terraces have been constructed to accommodate this change (left side of both photographs). Risers appear to be well built and not cultivated. Removal of indigenous vegetation on the hill has led to gully and rill erosion in 2008. The valley bottom is irrigated nowadays.

(Munro et al., 2008). These activities continue today over a very large region (Nyssen et al., 2007a). A key intervention has been the closing of strongly degraded areas to livestock, cultivation and indiscriminate tree felling. On the often naturally stepped and steeply sloped topography of the study area, these exclosures take the form of 200 to 2000 m long and 50 to 150 m wide vegetation strips, and cover up to 15% of the land (Descheemaeker et al., 2006a,b). In these now-protected areas (Supplementary data, photo-couples 5, 6, 7 and 13), increases in biodiversity, vegetation cover and density, and improvement in soil fertility correlate to the time that has elapsed since closure (Aerts et al., 2004; Descheemaeker et al., 2006c; Tefera et al., 2005). Exclosure establishment also enhances infiltration and biomass production, which together strongly impact on land rehabilitation.

3.3. *The firewood issue*

Most of the study area lies in Ethiopia's Tigray region, where 81% of households remain dependent on firewood for their energy needs (www.csa.gov.et). The exclosure policy has been and is a cornerstone in the dynamics of landscape recovery, whereby both population and vegetation density has increased. Firewood is available as a result of better biomass production and the use of bark, leaves and branches of the now widely spread eucalypts (as can be seen on most of the current photographs). Eucalyptus however, is generally expected to lead to increased soil erosion on account of reduced understorey cover; it is also a phreatophyte (Nyssen et al., 2006). Pankhurst (1995) noted, that as early as 1913, an Imperial Decree was issued to compel the uprooting of

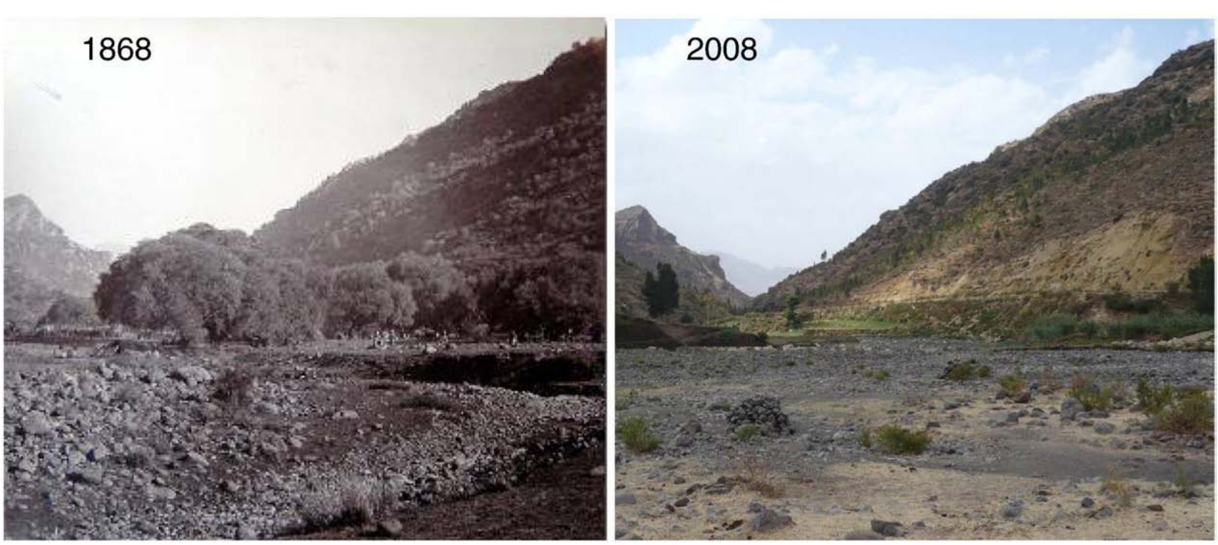

Fig. 4 – Meshig valley. The alluvial plain has been largely eroded, which also explains the disappearance of the grove at the centre of the 1868 photograph. Nowadays, the river bed has widened to the foot of the slope. We relate these changes to changes in hydrological conditions, especially stronger runoff responses due to land degradation up to the late 1980s.

eucalypts; but, for economic reasons (Jagger and Pender, 2003), this was never enforced. Nowadays, recommendations in relation to eucalypt afforestation in northern Ethiopia are more pragmatic and purposeful, being designed to avoid dense planting, with conservation works in planted areas, to avoid planting in valley bottoms, and to exclude livestock from the plantations (Nyssen et al., 2007b). Wood harvesting for urban consumption however still takes place on hillslopes in rural areas (Fig. 3). Better protection and management of remnant vegetation, enhancement of access to alternative sources of urban energy and changes in cooking habits (Asmerom, 1991; Bereket et al., 2002) should be top priorities so as to sustain the current positive trends.

3.4. *Physical soil and water conservation activities*

Physical structures, most notably stone bunds, have been built (Fig. 3; Supplementary data, photo-couples 3 and 10). Given the semi-arid environment of the Tigray uplands, the structures are designed to conserve both soil and runoff. Measurements on 202 field parcels (Nyssen et al., 2007a) have shown that stone bunds reduce soil loss on average to 32% of the pre-existing situation. Further positive off-site effects are runoff and flood regulation. From the technical, ecological and economic point of view, the extensive use of stone bunds, involving popular participation, is a positive operation (Nyssen et al., 2007a). Research in Ethiopia and elsewhere (Bekele and Holden, 1999; Boyd and Slaymaker, 2000) demonstrates that given the ecosystem services (Robertson and Swinton, 2005) resulting from farmers stone-bund building, current subsidies and incentives are justifiable.

3.5. *Gully and river morphology*

The repeat photography study indicates that there have been locally divergent patterns of gully and river bed evolution. The modern village of Hintalo (Supplementary data, photo-couple 9) was an ancient provincial capital of Tigray and a relatively large town in 1868. Soil surfaces appear more strongly sealed at that time, and more trees and shrubs were being cut, which can explain gullying induced by higher runoff coefficients. At other places, gullies were larger in 2008 than in 1868 (Fig. 2), but have stabilized. The increased number of gullies in Fig. 3 is certainly induced by the removal of remnant vegetation: current knowledge (Nyssen et al., 2006) indicates that gullying was enhanced after gradual environmental changes, including the removal of vegetation from cropland and slopes, and rill-like incisions grew into gullies that increased rapidly in critical periods such as during the 1980s drought. On the other hand, since 1995, with widespread conservation activities leading to runoff trapping on slopes and in the gullies, few new gullies have developed; gully banks have stabilized, and area-specific short-term gully erosion rates are down to an average 1.1 t ha^{-1} yr^{-1} (Nyssen et al., 2006). In a similar evolution, the two re-photographed rivers have widened since 1868 (Fig. 4; Supplementary data, photo-couple 10), yet parts of their beds became stabilized, a sign of recently decreased runoff response. Photographs of 1975 (Munro et al., 2008) also show that in that period active gullying was on-going as could be deduced from bank collapse, whereas in 2006 the same gullies, though larger, have stabilized with some vegetation growing on their banks.

4. Conclusions

This study of landscape re-photography covering 140 years of change shows that the status of natural resources in northern Ethiopia was very degraded in 1868, but has since then improved, and in some areas greatly improved. The increased ecosystem functionality is due both to improved vegetation cover and to the completion of physical conservation structures. The (apparently positive) impact of land reforms carried out since the late 1970s on land-use, vegetation cover and erosion processes needs to be further investigated. Exceptionally, degradation has continued in a few areas: mostly gullies and riverbeds have expanded since 1868; in several areas remnant natural vegetation forests are poorly managed.

Overall, this study invalidates hypotheses of the irreversibility of land degradation in northern Ethiopia and *a fortiori* in less marginal semi-arid areas. The study demonstrates furthermore that it is possible to reverse environmental degradation and provide ecosystem services for society in semi-arid areas where active, farmer-centred SWC policies (Stocking, 2003) with adequate levels of subsidies (Robertson and Swinton, 2005), enable small-scale farmers to stay on their land. Hence, the 'More People Less Erosion' hypothesis (Boyd and Slaymaker, 2000; Tiffen et al., 1994) has been confirmed in this particular semi-arid area where high rural population density compels farmers and authorities to improve land husbandry.

The anticipated positive changes to ecosystem service supplies (water availability, biodiversity, agricultural productivity, carbon sequestration, river regulation) in northern Ethiopia, resulting from changing land cover and management (Schröter et al., 2005), are of global significance. Future challenges to be met include the active development of a policy for sustainable urban energy consumption.

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Appendix A. Supplementary data

The full dataset of time-lapsed photographs and other supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.scitotenv.2008.12.016.

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