DESERTIFICATION AND CHANGES IN RIVER REGIME IN CENTRAL AFRICA: POSSIBLE WAYS TO PREVENTION AND REMEDIATION

JAN MOEYERSONS AND PHILIPPE TREFOIS

Royal Museum for Central Africa, Division of Geomorphology and Remote Sensing, Leuvensesteenweg 13 B-3080 Tervuren, Belgium, e-mail: jan.moeyersons@africamuseum.be; philippe.trefois@africamuseum.be

INTRODUCTION

Oral and geological evidence show a remarkable change in the hydrological behaviour of rivers in big portions of the African continent (Moeyersons, 2000). The change started some hundreds to some tens of years ago. Rivers which were perennial some generations ago, become gradually seasonal. The peak floods are higher than before and follow shorter after the rains. The low stages are lower than before (Fig. 1). This phenomenon evidences the change which took place in the alimentation mechanism of rivers. Rivers, mainly spring-fed, became gradually increasingly runoff-fed. This can only been explained in terms of declining soil infiltration capacity in the spring catchments (Fig. 2), what leads to a reduction in soil humidity. But decreasing soil infiltration capacity contributes to land degradation in several other ways (Moeyersons et al., 2006):

1. The general increase in runoff makes that spring catchments on the topographic threshold graph for gullying (Montgomery and Dietrich, 1994) are shifting from gully free conditions to gully prone conditions. The danger for badland development increases.
2. The development of gullies in a formerly gully free landscape contributes to a reduction in the water storage capacity of the soil and, hence, will also contribute to a dryer environment.
3. Gullies are highways for the quick evacuation of soil materials eroded from the water divide areas and thus favour soil degradation.

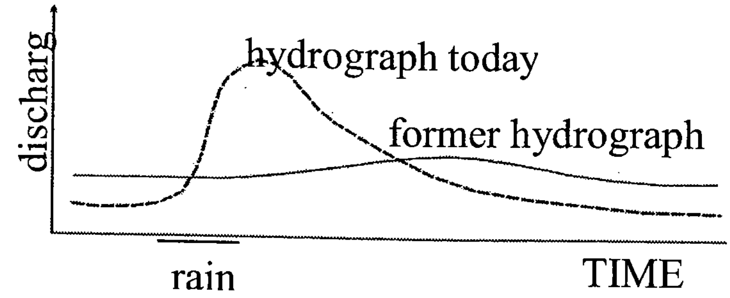


Figure 1. Evolution of the hydrographs

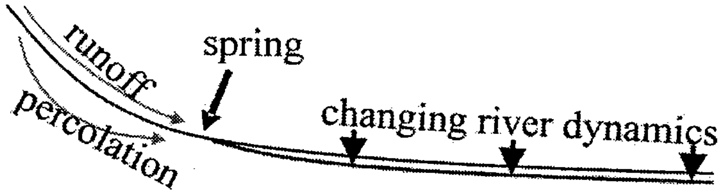


Figure 2. Evolution to more runoff

4. gullies can incise deep enough to become unstable and provoke mass movements.

The river beds, downslope of the springs, adapt to the new hydraulic conditions created by the occurrence of stream floods and flash floods. In flat areas, flash floods lead to widening of the stream channels and installation of braided river systems. Lateral erosion goes hand in hand with strong accumulation in the riffles. In steep areas, flash floods contribute to active vertical incision, which leads most of the time also to slope instabilities and mass movements.

The explained change in river regime is a frequently forthcoming phenomenon in Africa. Fig. 3 shows the regions where the phenomenon has been observed by one of the authors since the last 30 years and where, as a consequence, land degradation and desertification

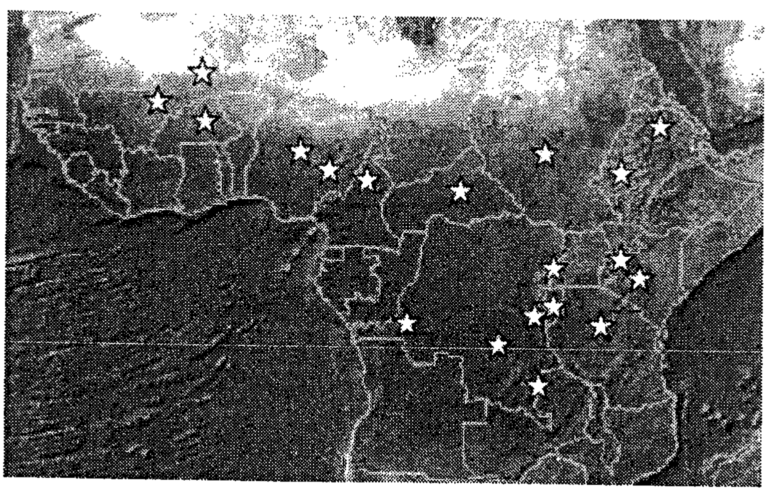


Figure 3. Changing river dynamics in Africa

are in progress. In a general way it concerns a belt in the savannas around the tropical rain forests. But also inside the tropical belt, big clearings and towns are affected.

It is known that forest clearing, overgrazing and agricultural intensification lead to decreased spring discharges and increasing runoff coefficients. But increasing rainfall variability as can be expected as a result of global climate change (Hulme et al., 2001; Dore, 2005) is also believed to play a role.

This article want to stress this type of situations as they occur along the Albertine Rift in Eastern D.R. of Congo, in Rwanda and Burundi. Firstly it aims to report on the material damage and even loss of lives, going hand in hand with the changes in hydrological behaviour of the landscape. Further, the article reports on geomorphological investigations, carried out in Rwanda in order to study the influence of soil use on the hydrological behaviour of slopes in Rwanda. Finally, this article will also explicitly mention the existing methods of soil and water conservation management which can contribute to 'normalisation' of the hydrological behaviour of slopes in the East D.R.Congo, Rwanda and Burundi.

EXAMPLES OF DAMAGE BY NATURAL RISKS: THE GRAVITY OF THE SITUATION

The Kivu-Rwanda-Burundi region seldom comes into the news as a result of environmental hazards. The only hazard, mentioned is of volcanic (Nyiragongo, 2002) or seismic (Bukavu, 02/2008) nature. Nevertheless, the whole region is currently affected by natural hazards, increasing in number and intensity every year. Included are sudden severe farmland erosion, river flash floods and inundations, deep gully incision, landslides and other mass wasting. Year after year the economic infrastructure of roads, buildings, bridges, farmland becomes increasingly damaged and losses of livestock, agricultural lands and food crops grow. Several dozens of people are yearly killed. In Bigogwe, Northern Rwanda some 20 people were killed by the inundations during the night of 12-13 September 2007. Flash floods in Uvira killed some 40 people in February 2002. Also unexpected variations in the water tables and lake levels are at stake. So it appears from remote sensing information that the Tanganyika and Kivu lakes and the swampy areas in northern Rwanda know a lower water stage today than in the 50's. Recently, the hydro-electric plants in Northern Rwanda and on the Rusizi river became in difficulties. Furthermore, gullying becomes an increasing problem in towns and especially in their extension zones: houses and road infrastructure are threaten by gully incisions and the accompanying bank instabilities. Towns like Kigali, Butembo, Bukavu, Uvira, Cyangugu, Bujumbura are typical examples. Although never reported, we are aware of numerous inundations, landslides and sudden gully incisions over the entire territory of Rwanda, Burundi and Kivu, occurring at least since the seventies. Without any doubt, several dozens of people did die. We are not aware of calculations of the total cost of these small and big disasters, but there is no doubt that they hamper the sustainable development of the whole region.

It is also a fact that these natural disasters increase in frequency and intensity since the last two or three decades. The reason is unclear. Many of these 'geomorphological events' occur during or shortly after meteorological conditions, extreme in intensity and/or duration. Maybe climatic change is at stake (Muhigwa, 1999). But some landslides at Uvira and Bukavu have been proven to have a seismic origin (Moeyersons et al., 2004). Finally, the increasing hydrograph irregularities of rivers could be the consequence of changes in land use, which lead to a change in hydrological response of the landscape, rivers becoming increasingly runoff sensitive instead of spring discharge sensitive like it was some time ago. In this respect, the importance of deforestation on the low river stage has been shown over a period of 20 years along a few forested areas in Rwanda (Rwilima, Faugère, 1981). This evolution reflects the general decrease of the soil infiltration capacity.

As part of the research programme 'Study and mapping of natural hazards along the Albertine Rift' by the division of 'Geomorphology and Remote Sensing' of the RMCA, an inventory of all types of erosion processes, taking the size of a 'hazard' have been inventoried in Rwanda and counter-measures have been identified. More recently, studies have been done in Bukavu, Uvira, in the Bujumbura area, at Kigali, and problem regions have been visited like the Rusizi valley and the Kanyosha valley in northern Burundi. Research on gully development in the town of Butembo is also going on.

GEOMORPHOLOGICAL RESEARCH IN RWANDA BY THE ROYAL MUSEUM FOR CENTRAL AFRICA (RMCA)

AIM

Since 1975, the geomorphology section of the RMCA is explicitly present in the area and field research has been done in Rwanda in order to study the influence of soil use on the hydrological behaviour of terrain on granite/gneiss and phyllite substrate. In the same time an inventory has been made for all types of erosion, triggered by runoff and percolating water. The role of soil use in these processes has been evaluated. Basic results are given by Moeyersons (1989; 2004).

MATERIAL AND METHODS

All hydrological and soil mechanical parameters have been measured with apparatuses belonging to the Laboratory of Experimental Geomorphology, KULeuven.

The infiltration capacity of the soils in Southern Rwanda has been measured by a portable rain simulator (Fig. 4), used to define infiltration envelopes (Smith, 1972).

The hydraulic conductivity has been measured in the field by a simple ring permeameter and in the laboratory by oedometer tests soil mechanical parameters like cohesion, shear resistance, have been defined by vane tests an/or mono-axial shear tests.

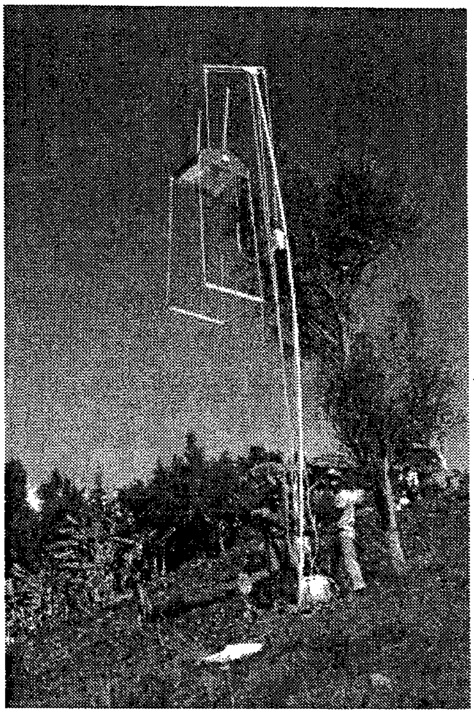
Measurements in the field of diffuse pluvial erosion have been done either in collector trenches below cultivated parcels (Fig. 5) or by means of erosion pins.

Creep measurements in the field have been executed by the measurement of displacement of tracers in so-called 'Young Pits' (Young, 1960).

The development of gullies was studied by qualitative and quantitative field observations.

Local soil and water conservation methods have been qualitatively evaluated in the field.

Teledetection methods, including aerial and satellite imagery analysis and mapping in GIS, are currently used to map landslides, deep gullies, inundation belts, severe farm erosion, river erosion.



log rainfall intensity in mm/h

log time (seconds)

Figure 4. Rain simulator (left) and infiltration envelope. Lower infiltration capacity corresponds to shift of the envelope to the left

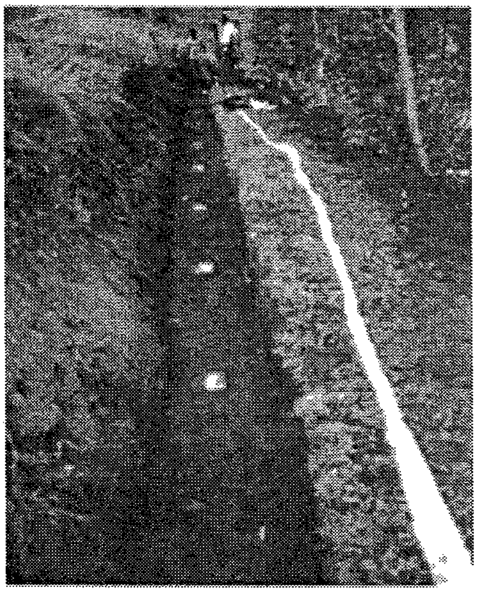


Figure 5. collector trench at Butare

RESULTS

A. THE INFILTRATION CAPACITY OF THE SOIL

The rain simulation experiments show that the infiltration capacity of the soil depends of at least the following variables:

- soil humidity: second runs on the same parcel, wetted already during the first test, show invariably a shift of the infiltration envelope to the left. This shows that the infiltration capacity will be lowest at the end of the rain. Rains, showing a sudden increase of intensity near to the end of the storm should produce proportionally more runoff than rains with their peak shortly after the start of the rain. On the scale of a rainy season with increasing soil moisture content, rains near the end of the season should produce proportionally more runoff and should be more erosive.

- The state of the soil: It is generally believed that hoeing the soil and the creation of a raw surface of soil aggregates increases the infiltration capacity of the soil. The runs with the simulator confirm this effect but indicate also that the effect of hoeing is very temporary on most soils in the area because of rapid slaking of the top soil, shaping a nearly impervious sheet.
- The vegetation cover just above the surface: runs in a bean field show the importance of soil cover: once the cover is above 80%, runoff is minimal and disappears completely at 100% coverage. Also some grasses like *Eragrostis* sp. and *Cynodon dactylon* reduce or even annihilate runoff at a high soil coverage.

B. EROSION ON PASTURE, RANGELAND AND IN EUCALYPTUS PLANTATIONS

The erosion pin measurements over 4 years at Rwaza hill, Butare (Moeyersons, 1990) show that land use highly determines erosion intensity. Measurements along 3 cross-sections of the hill show:

- higher erosion within or just downslope of Eucalyptus plantations without undergrowth;
- low or no erosion on grassy surfaces, but high erosion when the grass cover is interrupted either by overgrazing or along cattle tracks;
- no erosion and even fixation of sediments arriving from upslope within a small belt of low bush, composed of *Pteridium* cfr. *Aquilinium*, *Echinops* sp., *Helichrysum* sp., *Senecio* sp., *Vernonia* sp. and others.

The erosion measurements in the collector trenches result in the following conclusions:

- erosion in the rangeland – pasture – Eucalyptus (RPE) zone shows a seasonal trend to decrease during the progress of the rainy season (Fig. 6). Taking into account that, according to the rain simulation tests, the runoff coefficient should grow in the course of the season, the reduction in erosion has to be ascribed to an increasing soil protection by the grassy vegetation.

- Fig 7 shows the erosion dynamics 1981-1985 for the RPE area (trenches 1 to 4), compared to the dynamics of erosion in cultivated parcels (CP) (trenches 5 and 6). In spite of the seasonal trend of decrease during the course of the rainy seasons, the erosion in the RPE-area remains rather constant during measurements 1 to 18 Most spectacular are measurements 19 and 20 in the RPE belt, where erosion falls to less than one third of the level of former years after the zone had been declared by the owner as exclosure for free grazing cattle. This shows again the high protective potential of all vegetation close to the surface, in this case grasses, protected by trees.
- Fig. 7 shows also the erosion dynamics in cultivated fields. The erosion peaks in the cultivated fields (dashed lines 5 and 6) correspond to harvesting, weeding and all activities reducing crop cover or reworking the naked soil surface.

C. SLOPE STABILITY

New quantitative data have been collected that human activities not only can trigger diffuse and rill erosion but also important gully development (Moeyersons, 1991). It has also been shown that the

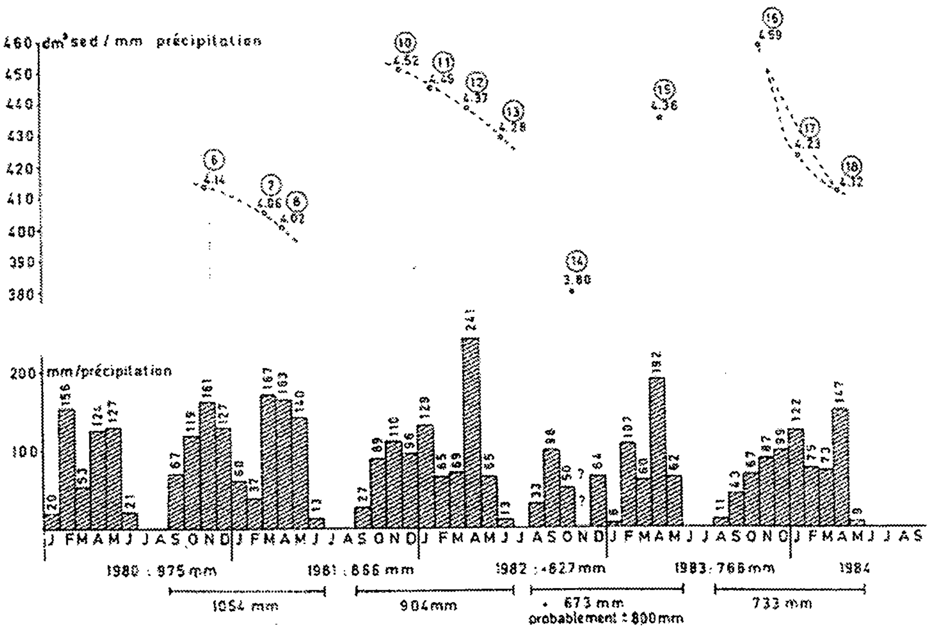


Figure 6. Volumetric determinations of sediment in collector trenches (dm³) divided by mm of precipitation since former determination, measurements 4 to 18. Some precipitation data are missing for the hydrological year 1982-83.

making of collector trenches as part of a soil & water conservation technique is not efficient when applied on slopes steeper than 20° (Moeyersons, 2003). Calculations show that cultivated slopes steeper than 20° to 25° are only stable if infiltration is diffuse, not concentrated. In all cases, studied so far, it appears that human activities result in an increase in local runoff or local forced water infiltration in the soil by artificial concentration of runoff, or in an increase in slope over which runoff waters have to find their way. This change is depicted in the Montgomery and Dietrich (1994) topographic threshold condition (Fig. 8).

CONCLUSIONS

In the highlands of Kivu, Rwanda an Burundi, forests prove to be the best ecological system, absorbing even on steep slopes most of

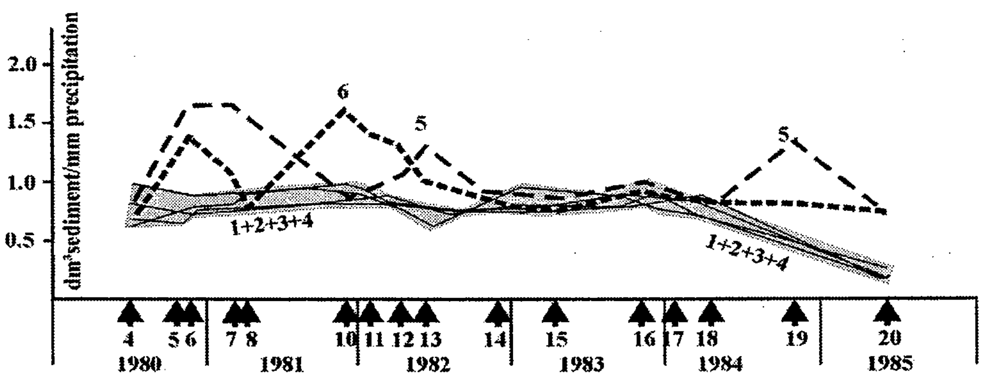
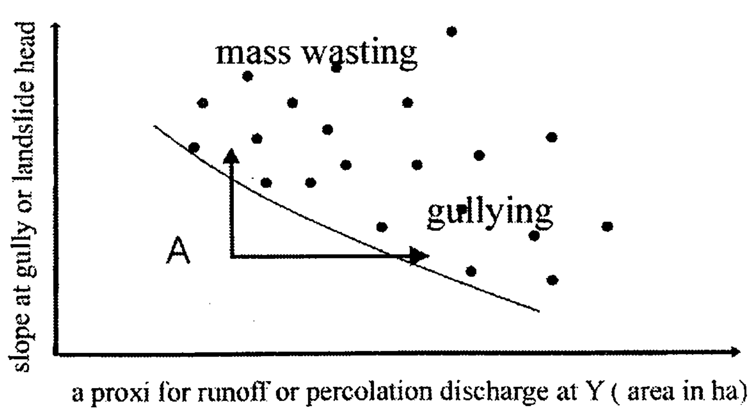


Figure 7. Volumetric determinations of sediment in collector trenches (dm³) divided by mm of precipitation since former determination, measurements 4 to 20. Hatched belt contains measurements in rangeland - pasture - Eucalyptus belt (collector trenches 1 to 4).

Figure 8. Increase in slope angle or in runoff/percolation discharge can bring point A above the envelope of risk to gullying and landsliding



the runoff. The presence of still growing valley peat formations in the forest of Nyungwe is good evidence for the absence of sediment transport on the slopes and for a river regime without important peaks. The same is true for the Bigogwe area in northern Rwanda, where gullying, severe slope erosion and river floods, increasing in size and number only occur since recent forest clearing. The daily experience shows that even in the context of increasing extreme meteorological conditions, forests and savannas with not overgrazed undergrowth lead to nearly complete infiltration of water into the soil. Even on steep slopes this does never trigger mass wasting, probably because the infiltration is diffuse. Therefore, if forests have to be cut, we should replace them by ecological systems having the same hydrological response as forests, i.e. creating a diffuse precipitation water infiltration into the soil. The role of vegetation in protecting soil and improving the soil infiltration capacity is well known (Köning, 2002; Rishirumuhirwa and Roose, 2002). According to our measurements and observations, we can forward several agricultural soil uses which reduce runoff to nearly zero, even on steep slopes:

- grassland, not over-grazed, with closed coverage;
- banana plantations with a soil covering undergrowth of legumes;
- coffee fields with good mulches;
- agro-forestry methods as mentioned by Ndayizigiye (1993), Ngenzi (1995), Köning (2002);
- tea plantations constitute a very nice and performing soil protective cover;
- reforestation and sustainable forest exploitation is also a possibility.

Soil-technical and biological mechanical methods for soil and water conservation are in use since a very long time. The first technique is called 'progressive terracing' and was introduced in the region after the second world war. It consists of the combined use of collector trenches and hays by pennisetum or another fixative plants. This system has been recommended only on slopes of less than 15°. If used on steeper slopes, it inevitably fails (Fig. 9) and even makes the situation worse by contributing to gullying (Moeyersons, 1989) and even landsliding (Moeyersons, 2004). The other technique is bench terracing, in Rwanda indicated as 'terrassement radical' (Fig. 10). Today, the technique is introduced in many plac-

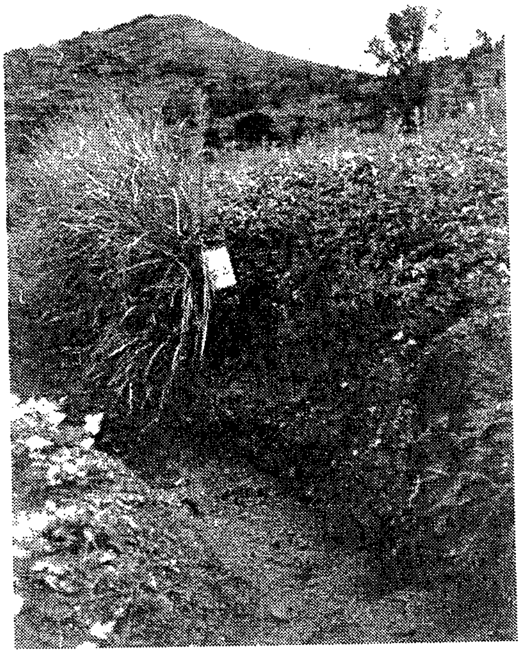


Figure 9. On steep slopes, the pressure by sediments retained by the hays is too high. The hay is pushed forward and finally fails as happened in the foreground.

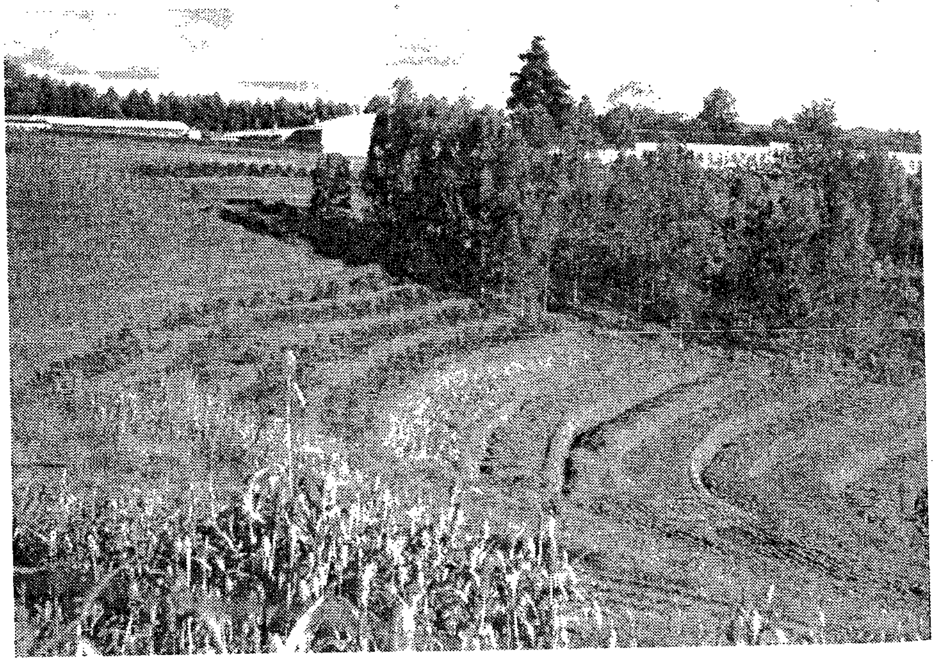


Figure 10. Bench terracing is in use in Rwanda since 1976. Never there have been reports on failures. The benches are slightly slope inward inclined and a 100 % infiltration is realised. This is absolutely necessary to prevent destruction of the whole slope by gullying.

es in the area. It was launched in the seventies at the agricultural center of Kisaro.

The hydrological deregulation of the slopes in the study area finds its origin in deforestation and consequent over-cultivation and over-grazing and constitutes a natural risk. The increase of the local capacity of studying this natural risk and the consequences like inundations, mass wasting, gullying, etc. is a first condition to combat land degradation by better alleviation and prevention and for an environmentally sustainable development.

REFERENCES

Dore, M., 2005. Climate change and changes in global precipitation patterns : what do we know? Environment International 31:1167-1181

Rwilima, Ch., Faugère, T., 1981. Evolution entre 1958 et 1979 du couvert forestier et du débit des sources dans certaines régions du Rwanda. Etude GEOMINES - AIDR, Bruxelles, 5 p.

Hulme, M., Doherty, R., Ngara, T., New, M., Lister, D., 2001. African climate change: 1900-2100. Climate Research 17:145-168

Köning, D., 2002. Conservation et amelioration des sols dans des systèmes-agro-forestiers au Rwanda. International colloquium: 'Land Use, Erosion & Carbon Sequestration'. IRD Montpellier, 23-28 September 2002. Book of abstracts, p. 56

Moeyersons, J., 1989. La nature de l'érosion des versants au Rwanda. Annales, Roy. Mus. Centr. Afr.., Tervuren, Series Economic Sciences, 19, 396 p.

Moeyersons, J., 1990. Soil loss by rainwash: a case study from Rwanda. Zeitschrift für Geomorphology, NF, band 34, heft 4, pp. 385-408.

Moeyersons, J., 1991. Ravine formation on steep slopes foward versus regressive erosion. Some case studies from Rwanda. Catena, 18, pp. 309-324.

Moeyersons, J., 2000. Woestijnvorming en mens in Afrika. Meded. Zitt. Kon. Acad. overzeese Wet. 46:151-170.

Moeyersons, J., 2003. The topographic thresholds of hillslope incisions in south-western Rwanda. Catena 50:381-400.

Moeyersons, J., 2004. Le rôle de la couverture végétale dans la redistribution des sédiments et du carbone des sols par le ruissellement : colline de rwaza, Butare, rwanda. Bulletin du Réseau Erosion 23 :99-112

Moeyersons, J., Tréfois, Ph., Lavreau, J., Alimasi, D., Badriyo, I., Mitima, B., Mundala, M., Munganga, D.O. & Nahimana, L., 2004. A geomorphological assessment of landslide origin at Bukavu, Democratic Republic of the Congo. Engineering Geology, 72/1-2 pp. 73-87

Moeyersons, J., Nyssen, J., Poesen, J., Deckers, J., Mitiku Haile, Kabeto Kurkura, Govers, G., Descheemaeker, K., Nigussie Haregeweyn, 2006. Climatic vs. anthropogenic desertification and sustainable agriculture in Tigray, Ethiopia. In Uhlig Siegbert, Maria Bulakh, Denis Nosnitsin, Thomas Rave (Eds): Proccedings of the XVth International Conference of Ethiopian Studies, Hamburg, July 20-25, 2003 Harrasawitz Verlag, Wiesbaden. pp. 1067-1077.

Montgomery, D.R. and Dietrich, W.E., 1994. Landscape dissection and drainage area-slope thresholds. In: Kirkby, M.J. (Ed.), Process Models and Theoretical Geomorphology. Wiley, Chichester, pp. 221-245

Muhigwa, J.-B., 1999. Analyse des perturbations dans le régime pluviométrique du Sud-Kivu durant les 50 dernières années. Mus. roy. Afr. centr., Dépt. Géol. Min., Rapp. Ann. 1997 & 1998, 112-121 Ndayizigiye,

F., 1993. La gestion conservatoire de l'eau et de la fertilité des sols au Rwanda. Thèse de doctorat Université Louis Pasteur, Strasbourg, 246 p.
Ngenzi, E., 1995. Facteurs et risques d'érosion hydrique au Rwanda à différentes échelles spatiales. Thèse de doctorat Université Louis Pasteur, Strasbourg, 261 p.
Rishirumuhirwa, T., Roose, E., (2002). Influence de l'érosion hydrique sur les propriétés et le taux de carbone des sols acides des hauts plateaux du Burundi (Afrique de l'Est). International colloquium: 'Land Use, Erosion & Carbon Sequestration'. IRD Montpellier, 23-28 September 2002. Book of abstracts, p. 79
Smith, R.E., 1972. The infiltration envelope: results from a theorethical infiltrometer. Journal of Hydrology 17:122-137
Young, A., 1960. Soil movement by denudational processes on slopes. Nature 188:120-122.