Assessment of Erosion and Soil Erosion Processes – a Case Study from the Northern Ethiopian Highland

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Introduction

Erosion of hill slopes is a natural process leading to a levelling of relief. The intensity of erosion depends on erosivity (energy of water causing erosion) and erodibility (friction of the soil against erosion). Additionally, human impact causes changes in landscape budget, predominantly in vegetation cover and in physical soil properties.

As soon as human intervention impacts morphodynamics soil loss is the result of soil erosion rather than natural erosion. Thus, it has to be emphasised that soil loss under natural environmental conditions corresponds to erosion processes, while soil loss in a system influenced by human intervention corresponds to the process of soil erosion. Erosion and soil erosion processes show the same characteristics; however, overall, soil erosion processes show a higher intensity. Consequentially, human activities intensify morphodynamics (OLDEMAN, 1988).

Due to the sharp increase of the population density in Ethiopia since the early 70ies (CIA 2002) pressure on landscape stability is extremely high. Next to area-wide cutting and collecting of firewood, deforestation for construction materials is very common as well as clearing for cultivation in areas that are not practical for agriculture (e.g. steep hill slopes or marginal land). High population density does not only cause intensive land cultivation, but also increases the movement of people within small areas, e.g. between villages for trading, between *Tukuls* (local houses) and to water sources for livestock watering and for irrigational purposes.

Research on erosion and soil erosion includes different catchments in the Ethiopian Highlands and determines landscape sensitivity on the one hand and the dominance of men-implicated erosion damages on the other. Mapping of soil erosion damages, of the location of settlements, trails and water places at two sites show that erosion damages are mainly caused by migrating men and livestock.

The two selected basins (***Dana, Beriti***) are located in the Northern Ethiopian Highlands and are characterised by a high intensity of erosion and soil erosion processes as well as a high population and livestock density. They are similar in their overall character of geology, soil type, climate and relief (relative relief of *Dana*: 0,059, *Beriti*: 0,033).

Field Research

Mapping erosion damages caused by the movement of people and livestock include recording of visible erosion features at different scales and the documentation of their overall character through photographs. The basins' direct erosion damages were registered. Single forms recorded included rills, gullies, and deep gullies – also classified as secondary and primary gullies. The length of the erosion form is shown proportionately in the map. Additional to single erosion forms badlands were recorded when single erosion forms cumulated and covered more than 30 % of the area.

Foremost, human impact is the factor that intensifies erosion processes and increases soil erosion. In the basins human impact is omnipresent due to the high intensity of land use. Nevertheless, next to the area-wide activities of tillage and pasture, only infrequently interfered by closed areas or reforestation areas, especially settlements, footpaths, and cattle treads cause a high pressure on landscape stability. Consequently, settlements as well as footpaths and cattle treads have been documented for this research.

Character and Erosion Damages of the Catchments

Dana Basin

The drainage basin of the *Dana* Reservoir covers an area of 7.7 km². Approximately 4000 people live in the watershed, most of them in the settlement of *Dana*. Additionally, along the watershed, various settlements are located mostly at the tops of the smaller hills or along the foot-zone of the higher ridges.

The *Dana* Reservoir was built in 1998 to supply water for irrigation of the downstream located farmland. The capacity of total sedimentation in the reservoir was calculated for a lifespan of 10 years, but already after three years high sediment yield of the head waters caused lasting siltation. The watershed of the *Dana* Dam is located in an intra-mountainous basin. At the base of the surrounding mountains extended colluvial sediments are deposited, whereas alluvial sediments are deposited in the centre of the basin. The *Dana* Reservoir is located in the centre of the alluvial basin. Four major river systems, characterised by u-shaped channels that are incised into the alluvial sediments, drain the alluvial basin and feed the reservoir. The development of that alluvial basin's distinct stream network started quite recently - only about 30 years ago. Field surveys clearly show, that the recent gully-system follows an older channel system, which's river beds used to be wider than today but less incised into the alluvial deposits. Thus, the relief of the alluvial basin today show typical characteristics of erosion terraces in a lowland area.

Rill erosion is the predominant process all along the colluvial zone below the *Darimu* settlement. Here, in most cases rill erosion is caused by poorly maintained terraces. The density of rill erosion is quite high overall and on each field rills can be detected. The rills are tributaries to the *Dana* River and cause severe erosion along the banks and have locally already reached badlands character. Intense rill erosion also occurs west of the settlement *Adisukebele* between the street and the dam site. In this area rill erosion is mainly due to overgrazing and intense cattle tread. Furthermore, rills are tributaries of the gullies. Rill erosion also occurs in the colluvial zone east of the village *Dana*, however, it is less severe. Rill erosion is mainly due to bad maintenance of the existing terrace structures.

Next to rill erosion gully erosion is an important and landscape forming process in the *Dana* watershed. Gully forming processes in the *Dana* basin have to be differentiated into:

- Formation of deep gullies respectively u-shaped channels, which occur predominantly in the alluvial deposits of the basin (developed since the early 1970ies);

- Formation of gullies that are mostly tributaries of deep gullies and drain the colluvial zones (secondary gullies), and
- Formation of large rills, which are located in the colluvial zone and in the basin centre.

Figure 1: Development of Gullies in the Dana Catchment

U-shaped channels in the basin centre, once developed from gullies, currently have a total extent of approx. 6.5km (total channel length). The development of these u-shaped channels – that makeup a channel network – started to develop about 30 years ago in the area where the *Dana* Dam is located today. As gully development coincided with deforestation of hill slopes and increasing tillage, it can be concluded that gully development was caused by increased surface runoff as a consequence of changes in vegetation cover and land management.

It should be emphasised that these younger gully-systems are all located in the colluvial and alluvial zones below settlement areas. Their development is mostly caused by high rates of surface runoff generated on the poorly vegetated and highly compacted areas around the settlements. Moreover, along footpaths this surface runoff is channelled and, thus, can develop linear erosion forces. In sum, development of secondary gullies does not occur below headwater areas without settlements. At present, most of the gullies show numerous indicators of stagnating incision – e.g. meandering channels and deposition of valley beds.

In particular, a high level of gully formation processes with a development of badland areas occurs in the immediate neighbourhood of the dam site. The reservoir (Figure 2) is used by people and livestock as a source for drinking and bathing water. They cause disturbance of soil structures and soil compaction along the shore of the reservoir. Due to the compaction rate infiltration decreases and surface runoff increases. The disturbed soil structure results in an increased erodibility of the soil. Overall, it can be concluded that the severe badlands around the *Dana* Dam site developed in consequence of the retaining of the *Dana* River during the last three years.

Figure 2: Colluvial / alluvial zone, dam and major channels

Additionally, the impact of a street that passes through the catchment in its northern and eastern part along the rim of the colluvial zone has to be considered as a factor that greatly influences soil erosion processes. While the street causes a break of slope length it primarily appears that its construction causes a decrease of soil erosion. However, road construction also coincides with the construction of drainage channels parallel to the road that lead into the already existing drainage system. Additional discharge from these ditches causes incision and a reactivation of the – in most cases –previously inactive gully-systems. In comparison, the development of the badland area below *Adisukebele* (Figure 3) is influenced by a range of factors.

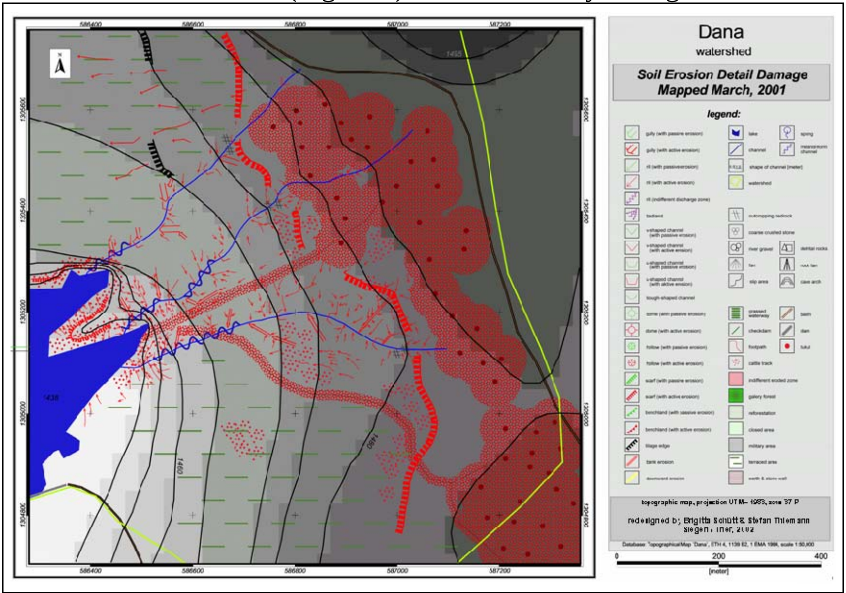

Figure 3: Soil erosion damage mapping closed to *Adisukebele*

Further road construction in 1999 and 2000 caused yet again a disturbance of these very sensitive gully-systems and reactivated them. These circumstances in addition to the intensive pasture and the consequential poor vegetation cover – due to the high frequency of men and livestock migration between the settlement and the reservoir – caused development of a badland area between the settlement *Adisukebele* and the dam site. The degree of damage increases with decreasing distance to the reservoir.

Pre-rill and rill erosion in the watershed (Figure 4) of the *Dana* Dam site are mainly caused by the change in vegetation cover through deforestation, clearing and overgrazing. Implemented soil conservation measures, such as contour ploughing and terrace and stone bench construction, only have a limited effect due to poor maintenance.

Figure 4: Rill erosion north of *Adisukebele*

In contrast to these area-wide soil erosion processes – that only vary in intensity – gully erosion predominantly occurs in the immediate neighbourhood of footpaths running perpendicular to contours. Almost all gully-systems recorded run along footpaths. The impact of channelled runoff along footpaths is alarming and intensified by the heavy soil compaction and by poor infiltration rates (see Fig. 5).

Along the dam's waterside badlands developed in consequence of the previously mentioned high frequency of movement of people and livestock due to the reservoir's function as a watering place. In contrast, west of the *Darimu* settlement badland areas developed due to overgrazing, whereas west of the northern fringe of the *Darimu* settlement badlands occur along the *Dana* River and are mainly caused by rill erosion attributed to poor maintenance of terrace systems needed in this area of high relief.

In sum, most of the active and recently developed gully-systems have their origin below settlements or along footpaths, where topsoil is highly compacted and hence the infiltration rate reduced. Consequently, the construction of check dams in the colluvial and alluvial zones will only have a sustainable effect on gully erosion if, in addition, in the source areas corresponding measures are implemented. Therefore, it is indispensable that, especially in the areas highly endangered by gully-erosion, movements of the inhabitants are regulated and wild footpaths are prohibited.

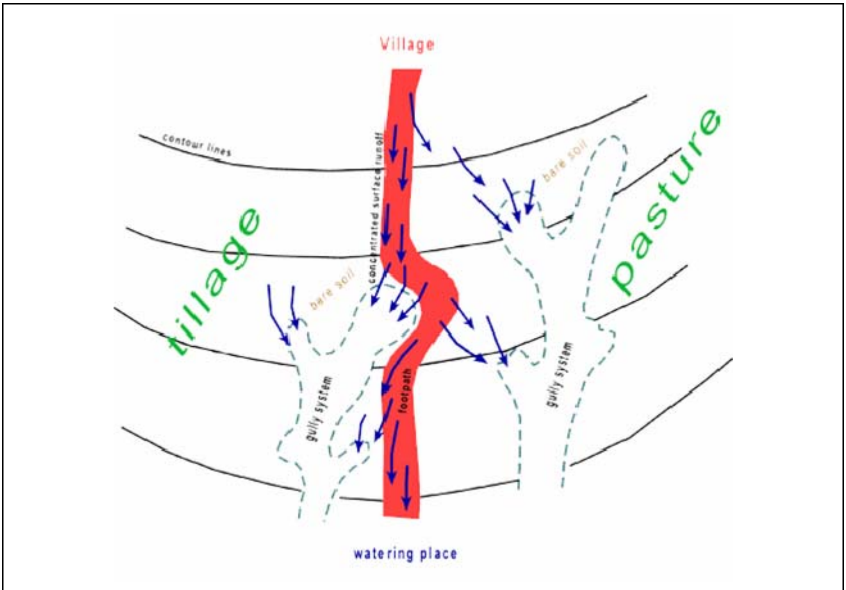

Figure 5: Typical interaction of footpaths and generation of gully-systems:

Footpath perpendicular to contour lines (shortest way from village to watering place)

Tillage and pasture area wide coming along with bare soil (e.g. overgrazing)

Soil compaction on footpath associated with concentration of surface runoff

Gully-heads closed to footpath

Beriti Basin

The construction of *Beriti* Reservoir started in 1982 to store water for irrigation of downstream farmland and to supply water to the cement factory located in *Mokoda*. It is located at an altitude of 2454 m a.s.l. The drainage basin of the *Beriti* Dam covers an area of 35.3 km².Basic volcanic strata characterize the petrography of the catchment area.

The area of the *Beriti* watershed is densely populated with most of the settlements located along the water divide in the plateau area and the escarpment respectively. The slope areas along the escarpment as well as the fans and colluvial deposits at the base of the escarpment or the smooth slopes in the area of the plateau divide are preferred for farming. The alluvial zone is used as pasture wherever wetlands or swampy areas occur. Most parts of the escarpment are used for pasture due to the steep slopes.

Along the eastern water divide the transition between the plateau area and the escarpment in most cases takes place abruptly. The area is densely populated with only a few tillage areas. The road and trail network is highly developed and very dense, showing damage by cattle tread predominantly parallel to the main road, where movement of people and livestock is extremely high. The occurrence of trees and shrubs is restricted to the surrounding of the settlements. Slope areas of fan and colluvial deposits are due to the good drainage conditions and predominantly used for growing barley. Contrarily, the alluvial zones are, due to the widespread wetlands and swampy areas, used for pasture. Only recently the cultivation of maize has been initiated in some locations along the alluvial zone.

Damage resulting from soil erosion in the *Beriti* watershed is predominantly caused by cattle tread (Fig. 6), particularly around settlements, along footpaths and parallel to the road, as well as below the settlements along the direct path to the watering place (Fig. 7). As a result, damage caused by soil erosion due to soil compaction can be attributed to the intense movement of livestock and people and frequently leads to the development of badlands.

Figure 6: Cattle tread

Figure 7: Gully parallel to footpath

The appearance of gullies and rills is predominant at three types of locations:

- Footpaths and zones of cattle tread,
- Around the contact springs that are predominantly watering places for livestock,
- Along field boundaries that frequently serve as 'guidance' for footpaths.

In these areas damage caused by soil erosion is most severe where footpaths and cattle tracks run straight downhill (Fig. 11).

Figure 8: Badland development caused by cattle tread

Figure 9: Grassed waterway

In all areas most severe soil erosion damages occur corresponding to the disturbance of soil structures and intense soil compaction caused by cattle tread and movements by people along footpaths and parallel to roads as well as around settlements. Figure 10 shows that even in smooth relief gullies and rill erosion develop.

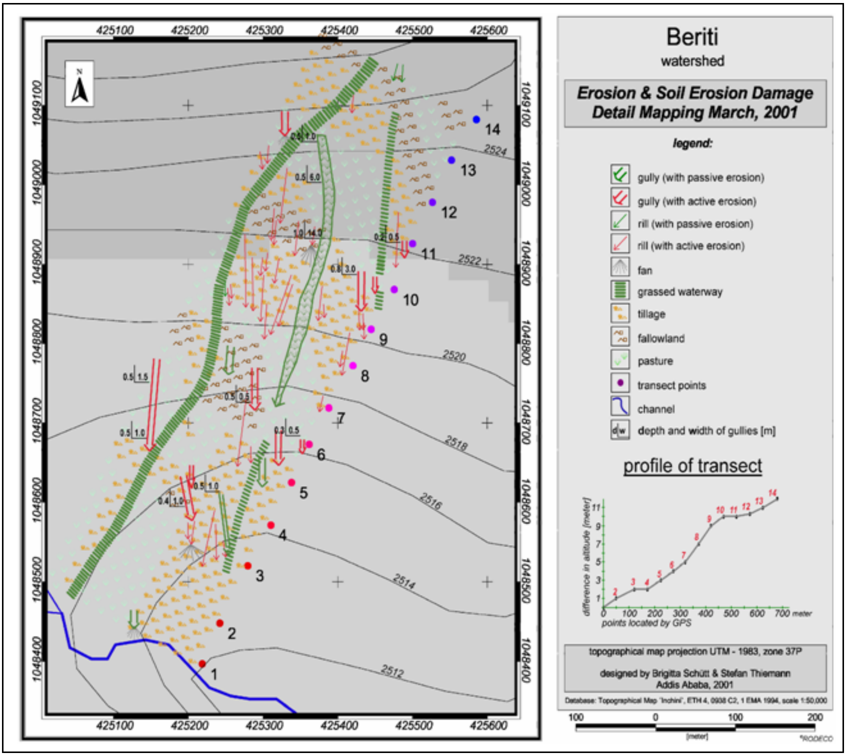

Figure 10: Erosion and soil erosion map in the northern part of the basin

Conclusion

The field study and the mapping and modelling of erosion and soil erosion in these two catchment areas show the direct interrelationship of natural processes and human intervention. Due to the high pressure on landscape stability, processes caused by people and livestock extremely intensify natural erosion processes.

The outlined ‘man-made’ factors that cause and intensify soil erosion processes include cultivation, livestock farming, the density of settlements and the migration of people and livestock. Soil erosion processes are altogether very similar. Due to the compaction rate of the soil infiltration of water decreases and surface runoff increases. Disturbed soil properties also lead to an increased erodibility of the soil. Therefore, it can be concluded that several erosion forms and badlands develop consequentially to clearance, overgrazing, and migration of people and livestock as well as the bad maintenance of existing soil conservation measures (i.e. terraces). The development of almost all gully-systems indicates the alarming impact of channelled runoff along footpaths and cattle treads.

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