Soil Erosion Forms in the Simen Mountains-Ethiopia (with map 1:25 000)

By Hans Hurni*

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Summary

Soil erosion has become a basic problem for the inhabitants of the Simen mountains. The map in this article shall contribute to the basic knowledge, which should lead to a soil conservation program for Simen**. Damage caused by soil erosion was mapped in the autumn of 1974 by means of

1) differentiation of the cultivated land into four classes of damage: Extremely, heavily, moderately and lightly damaged areas.
2) depth of the topmost black horizon (which is essential for cultivation), presented areawise.
3) forms of water erosion.

Soil erosion principally occurs on the barley fields (cultivated land). Tendency to damage according to slope aspect, form and incline is clearly shown. An evolution of the forms of soil erosion can be derived. The need for protective measures against soil erosion is evident. Together with studies about soil erosion processes, this map will contribute to an appropriate soil conservation program.

Zusammenfassung

Bodenerosion ist für die Bewohner des Semiengebirges zu einem Problem von lebenswichtiger Bedeutung geworden. Die in diesem Artikel publizierte Karte wurde als Grundlage und erster Schritt eines Bodenkonservierungs-Programmes zur Bekämpfung der Bodenerosion und Erhaltung der Bodenschicht erstellt**. Mit ihr soll das Ausmass der Schädigung durch Bodenerosion festgehalten werden. Die Karte zeigt den aktuellen Zustand im Herbst 1974. Bodenerosionsschäden wurden dargestellt durch:

1) Klassierung der Ackerflächen in verschiedene Schädigungsgrade: Sehr schwer, schwer, mässig und gering geschädigte Flächen.
2) Mächtigkeit des obersten, schwarzen Horizontes, der für den Getreideanbau von grundlegender Bedeutung ist und stellenweise schon ganz erodiert wurde.
3) Formen der Abspülung.

Die Karte zeigt, dass Bodenerosion hauptsächlich im bebauten Ackerland auftritt. Tendenzen der Schädigung nach Exposition, Form und Neigung des Hanges werden deutlich. Eine Genese der Bodenerosionsformen ist erkennbar. Möglichkeiten für Schutzmassnahmen gegen die Bodenerosion sind vorhanden, jedoch müssen zuerst noch die Bodenerosionsprozesse untersucht und für die praktische Anwendung miteinbezogen werden.

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** This article is a slightly modified translation of the article "Bodenerosion in Semien – Äthiopien", Geographica Helvetica, H. 4/1975: 157–168 by the same author.

Résumé

Pour les habitants des montagnes du "Simen" l'érosion du sol revêt une importance vitale. La carte publiée dans cet article sert de base à un premier programme de préservation du sol afin de combattre l'érosion et de sauvegarder la terre**. La présente carte permet d'évaluer l'étendue des dommages provoqués par l'érosion. La carte représente la situation en automne 1974. Ces dégâts sont décrits de la manière suivante:

1) une classification des terres arables en différentes zones de dommages: dommages très importants, importants, moyens, insignifiants.
2) l'épaisseur de la couche supérieure de l'horizon foncé, qui est d'une importance primordiale pour la culture des céréales, et qui est par endroit totalement érodé.
3) les formes de l'érosion par l'eau.

La carte démontre que l'érosion apparaît surtout dans les terres cultivées. Des tendances aux dommages, selon l'exposition, la forme et l'inclinaison des pentes sont distinctes. Les origines des formes d'érosion sont reconnaissables. La possibilité d'établir des mesures de protection contre l'érosion du sol subsiste; cependant les processus d'érosion doivent être encore étudiés et inclus dans la pratique.

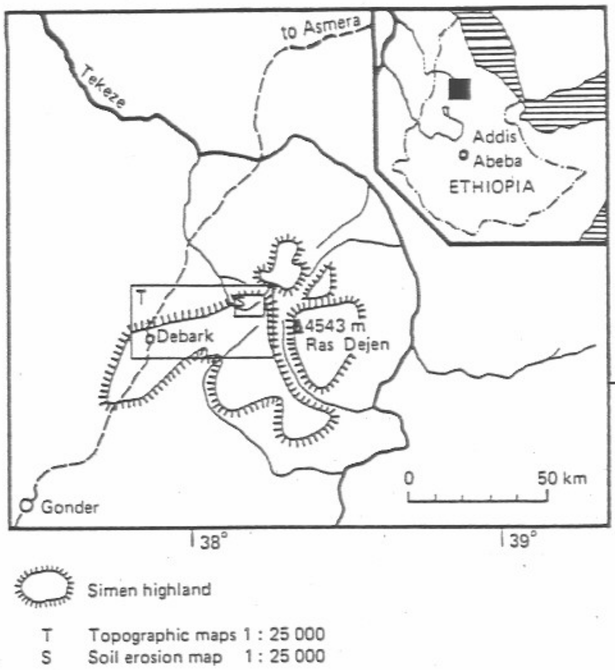
1. Introduction

The upper Jinbar valley, object of this soil erosion map, lays in the central highland part of the map "Simen Mountains National Park 1 : 25 000" by MESSERLI, STÄHLI and ZURBUCHEN (1975), between 3200 and 4000 m above sea level (fig. 1). The lower part of the valley is cultivated with barley up to the natural climatic limit of 3400 to 3700 m, the upper part is covered with mainly erica trees (Erica arborea) up to an elevation of 3600 to 3800 m. In higher altitudes, above the tree line and the cultivated area, there is a mountain steppe used as pasture.

The climate is a seasonally wet tropical one, but characterized by the high altitude, and it has medium temperatures with little annual, but high diurnal differences (between 2 and 12 centigrades on the average). Most of the rainfall is in the summer months (over 1200 mm). During the rains, the village of Gich is usually covered with fog. (Gich lays in the center of the soil erosion map, and has about 700 inhabitants or 130 houses.)

Basic food for the inhabitants of the upper Jinbar valley is barley. Each side of the valley is ploughed every second year, while the other side lays fallow. People plough any slope up to 80 % inclination with a pair of oxen, without being aware of the damage caused by soil erosion. (The plough is made of wood with a coulter.) Wide parts of the cultivated area are already extremely damaged by soil erosion.

Figure 1: Location map



The laws of the Simen Mountains National Park prohibit people from extending their cultivated land into the last remaining forests. If their existing land is not to be destroyed within a short time, measures against soil erosion have to be initiated as soon as possible. The soil erosion map included shows the existing damage, analyses soil erosion forms and helps to find appropriate patterns of land use with soil conservation measures.

2. Soil erosion

Soil erosion is caused by man's impact on nature, he disturbs the natural rate of soil formation and soil reduction, and causes an accelerated process of soil movements. Denudation, sheet erosion, rill erosion, gully erosion and accumulation are the forms of soil erosion, caused by water and wind (SCHULTZE 1952: 4; RICHTER 1965: 2). Soil erosion parameters such as long and intensive rainfalls, steep and long slopes, and fallow areas, especially cumulate in mountain areas. Soil is removed but not replaced, yields diminish, and men are forced to seek for more (and in consequence steeper) cultivated land. Such a process becomes catastrophic within a short time, if appropriate measures are not taken against it immediately. Adapted soil conservation measures however can only be found, if soil erosion has previously been studied thoroughly.

There are two ways to study soil erosion: One is to measure and study the damage caused by soil erosion, the second is to study the soil erosion processes. To carry out the first method, a system to describe the forms of soil erosion has to be found; i.e. how to show it on a map. For the second method, the soil has to be observed when soil erosion occurs; knowledge of climate, soil, topography, cropping and soil conservation measures are essential.

This article is the result of the first method: Mapping the damages of soil erosion. Field observations for the second method were done in 1975 and 1976, they will be published in a later article (in preparation). Together, these two methods will allow to evaluate factors which influence soil erosion processes and also lead to appropriate soil conservation actions.

Soil erosion damage can be studied in two ways: One is to study the damage done to the soil profile by diminishing the uppest horizon, the other is to map the damage which is visible on the soil surface (rills, gullies). A combination of both these methods will lead to a most precise soil erosion damage map. Before mapping the soil erosion, it is however essential to study the soil profiles of the Jinbar valley in their undisturbed natural conditions as well as to summary all soil erosion forms which occur in it.

2.1. *The soil profile*

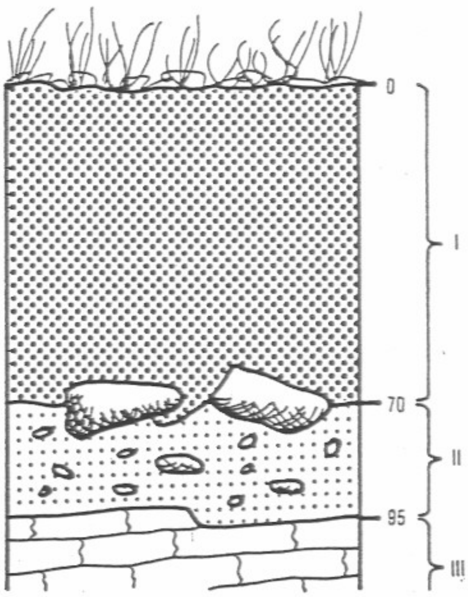
If there were no human influence, the whole upper Jinbar valley would have had a more or less uniform soil profile. In the upper part of the valley, where only woods and grassland occur, damage by soil erosion is not apparent and therefore the soil profiles could be studied in their almost natural conditions. Results of a mineral analysis by the Department of Mineralogy, University of Berne (Prof. Peters) with soil samples by Prof. Messerli (Department of Geography, University of Berne) were available. With little restriction, the soil can be typified in an ideal profile (fig. 2 and on the map).

The whole pedon can be classified as an ANDOSOL. Laboratory analyses however are not yet accomplished, they will be published in a later article. SEMMEL (1964: 485) did soil studies in Gojam and found soils of the order of INCEPTISOL in the similar altitudinal belt (called "Dega", the Amharic word for highland over 2800 m).

2.2. *The soil erosion forms*

The many different forms of soil erosion, which can be seen in the barley fields and around the village of Gich, have to be classified in order to present them on the map. The erosion forms

Figure 2: Ideal Profile



I Black horizon
II Brown horizon
III Basaltic rock

Description:

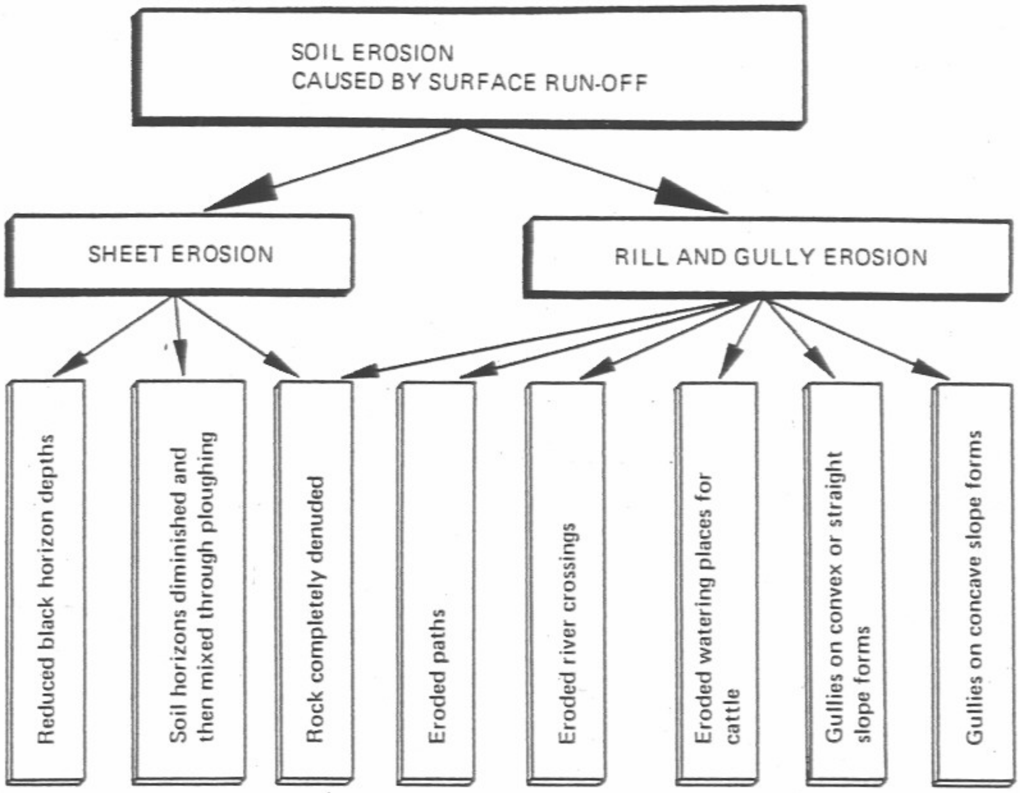
I Black horizon: Very fine-grained, mouldy black soil, which dries out quickly from the top in the dry season and changes to a brown colour. Many sharp cornered and rounded corns of quartz and feldspar show a secondary supply of volcanic material (ashes). The depth of the black horizon, which varies slightly with the slope form, is about 70 cm on the average.

II Brown horizon: It consists of a clayey, silty, yellow-brown matrix with a lot of stones (diameter 1–10 cm). Quartz and feldspar corns show that I and II correspond pedogenetically. The depth of the brown horizon — if existant — varies very much from a few centimeters to meters. On its top, erosion seems to have diminished the brown horizon before the uplay of the black one. Rills and gullies are proof of such an erosion phase. Since it has a lower limit at about 3000 to 3300 m above sea level and becomes deeper with higher elevation, this horizon seems to correlate with the young Pleistocene glaciation on the very tops of some Simien mountains.

III Basaltic rock: The rocky underground is weathered to a high degree, even if the porphyric texture remained. Crystals and the matrix are completely transformed into clay minerals and amorphic substance. Remnants of an old cambisol between II and III are sometimes existant.

caused by surface run-off are sheet erosion, rill erosion and gully erosion (BENNET 1955: 59–70). Wind erosion forms are negligible in Simen. The three groups of water erosion had to be modified slightly for Simen in order to be as realistic as possible. Figure 3 shows the correlation of the different soil erosion groups as they were used to present soil erosion damage on the map.

Figure 3: Soil Erosion Forms



3. The soil erosion map

Since there have not been soil erosion maps in Ethiopia before, an adapted legend had to be found to describe the soil erosion damage in Simen. The map included is an éxperiment in mapping soil erosion in a way that it contributes to soil erosion process studies as well as to soil conservation measures.

Therefore single runoff damage forms were mapped as well as the damage dimensions in different area units, and the depth of the top black horizon in areas where soil erosion had not destroyed it completely.

To describe the damage dimensions, we used the fact that the whole upper Jinbar valley has got the same soil formation with black and brown horizon. The proportion between parts with damaged and parts with undamaged horizons was used to indicate the severity of soil erosion. In 1956, STEINMETZ had used a similar method developed by Kuron and Jung (JUNG 1953) to describe soil erosion and soil usability.

With these elements:

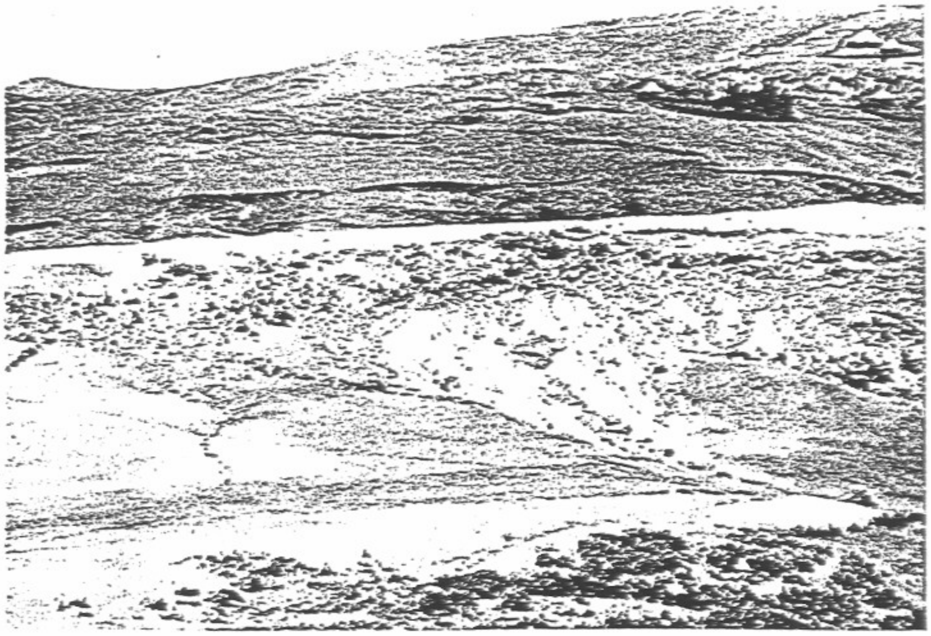
- damage dimension classifications,
- black horizon depth classifications,
- surface run-off damage forms,

it was possible to describe all forms of sheet, rill and gully erosion as well as to show where soil conservation measures will be most urgently required. The following chapters give explanations and contributions to the map's legend.

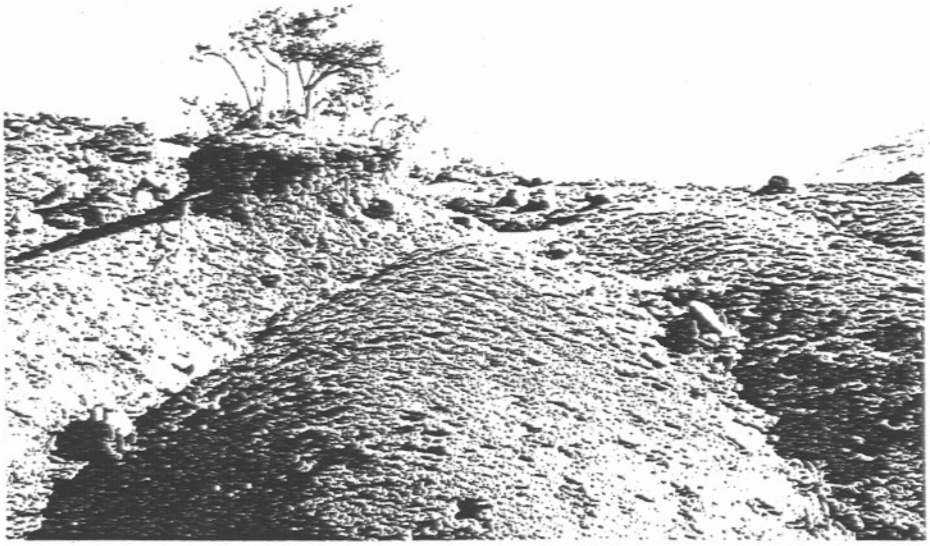
3.1. Woods and grassland

Woods and grassland occur in the higher area of the upper Jinbar valley, where either climatic limits or the law of the National Park prevent people from cultivating also this part of the valley with barley. The only spots where soil erosion occurs, are eroded paths caused by cattle, river crossings and watering places. The rest of the soil is protected by the thick mountain steppe and the Erica woods.

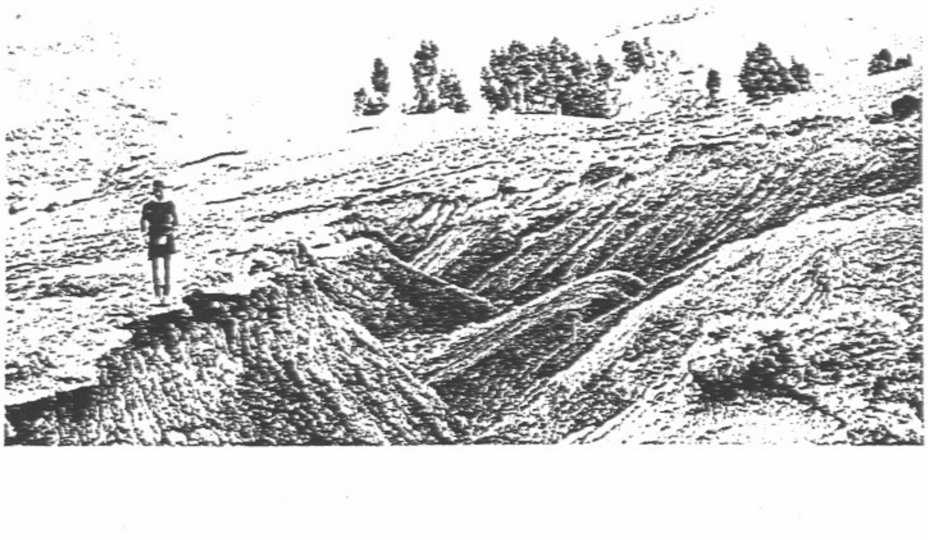
Knowledge of the depth of the top black horizon in this undestroyed part will enable us to see whether there was any reduction of the same horizon in the cultivated area. On about 200 representative points, soil samples of the black horizon have been measured in depth and compared with elevation, slope exposure, slope form, inclination and vegetation cover. Results of the statistical evaluation can be summarized by three statements:



Typical Eastern-exposed slope in the Jinbar valley.
The soil is extremely damaged by soil erosion. In many places the rock is completely denuded. Gullies are numerous. Yields are minimal.



Bushes retain some earth in extremely eroded areas. On both sides of the bush, gullies are washed into the weathered basaltic rock.



Immense qully on one of the barley fields of the Jinbar valley.

1) The black soil depth does not vary with elevation, exposure, and vegetation, but is 68 cm on the average with little average differences (± 3 cm).
2) The black soil depth slightly diminishes with increasing slope inclination: 0–33 %: 71 cm, 34–69 %: 61 cm.
3) The black soil depth significantly varies with the form of slope:

		(depth samples)
Strongly convex form:	55.0 cm average	27
Convex form:	62.4 cm average	33
Straight form:	69.5 cm average	81
Concave form:	77.5 cm average	46
Strongly concave form:	81.1 cm average	15

The 200 soil depth sample points with their parameters, slope form and inclination, made it possible to present the black horizon depth areawise in the woods and grassland. Further 300 soil depth samples were taken in the lightly damaged areas of the barley fields and also presented areawise. Knowing the soil depth in its natural condition (the uncultivated section of the valley), allows to show the effect of sheet erosion in the barley fields. (Chapter 3.3. and 4.2. will contribute to this question.)

3.2. Barley fields

The whole of the lower part of the valley (beyond Gich village, which is marked with black points on the map), is used for crops (barley fields) presented on the map in the four colours yellow to red. These colours represent damage dimensions, and indicate the general extent of the cultivated area. Generalized terms were used necessarily to describe the many different small forms of soil erosion. We had to do such a generalization, because it was not possible to present single erosion forms with this map's scale: 1 : 25 000 (1 mm represents 25 meters).

The generalization was to divide the barley fields into area units (greater than 600 m^2), limited and selected by soil erosion damage dimensions and topographic parameters such as slope, slope aspect and form of slope. In each unit, it was estimated what percentage of the total of the unit area has destroyed soil horizons (through reduction of the black horizon and ploughing into the brown one, or through rills and gullies). As results, we got four classes of soil destruction:

Greater than 60 %	extremely damaged
40–60 %	heavily damaged
20–40 %	moderately damaged
Less than 20 %	lightly damaged

An example: If less than 40 % of a unit area had a normal soil profile with black and brown horizons, i.e. if there was more than 60 % of the soil horizons mixed and disturbed, the unit was classified extremely damaged.

All units of the barley fields were classified into the four colours. On the map, the original area units are not presented again, but only the summarized four classes of damage.

Besides this general classification, damaged spots (such as completely eroded soil, etc.) were mapped to scale, and the depth of the black horizon could be presented areawise in lightly damaged areas with the 300 soil depth sample points (as already mentioned in 3.1.).

3.3. Depth of the black horizon

The soil depth measurings in both the woods and grassland and in the barley fields are basic data for a special study about sheet erosion. Comparison between soil depths in the undisturbed woods and grassland (200 samples) and the lightly damaged barley fields (300 samples) will be interesting (see 4.2.). The 200 samples in the uncultivated woods and grassland served as indicators of the natural soil depth, related to slope inclination and form (see 3.1.). The measured depths, varying from 25 to 110 cm, were classified in four classes: >80, 60–80, 40–60, and <40 centimeters, and presented areawise. In the lightly damaged barley fields, where the depth samples are twice the density of the uncultivated section (300 sample points on half the area of the woods and grassland), they will give a much more exact evaluation for the area. Because of the map scale these single sample points could not be presented on it (overloading of the map).

3.4. Damaged spots

Damaged spots as results of linear erosion occur in both the woods and grassland and in the barley fields. Spots where the soil has been eroded to the rock (rock completely denuded), indicate the final phase of soil erosion. They are mapped in a strong red colour and to scale.

Places where soil horizons have been mixed through ploughing, are marked with three red dots. In these places the black soil has been reduced to about 30 cm, so that ploughing goes through it into the brown horizon and brings its stones to the surface. These places appear mostly on convex slope forms, where the black horizon was never very deep. Hydrologically, such places are drier and allow a quick drying out of the soil when not covered by vegetation. Erosion by wind and water will be stronger there and reduce the top horizon until ploughing goes deeper through it into the brown horizon or weathered rock. These places are very important for initial soil erosion processes. In the extremely damaged areas, these places were not mapped because most of the soil was mixed or reduced in any case.

An accumulation of soil removed from the slope above, is frequent in extremely damaged areas and varies from a few centimeters to meters. Those areas can well be used for cultivation, even if many of them have secondary erosion with gullies.

Damage caused by cattle such as eroded paths, river crossings or watering places have been mapped where they might initiate more soil erosion.

Gullies were differentiated in their depth and in the form of slope where they exist.

4. Interpretation of the soil erosion map

The map responds to the following demands:

1) Damage caused up until 1974 is mapped and will give the possibility of comparing with 1974 in later years.
2) The map shows different parameters which influence soil erosion, such as slope aspect, inclination, vegetation, form of slope, gullies.
3) The total soil loss on any slope from the beginning of human cultivation until 1974 can be estimated (but not the annual soil loss). On the average, this loss is about 1000 metric tons per hectare, or about 15 cm in soil depth (HURNI, in preparation).
4) If larger areas than the upper Jinbar valley are investigated for soil erosion in Simen, the present work serves as a model and comparison area.
5) The map is useful as a contribution to basic data for soil conservation.

Each of the three elements: Damage dimension classification, depth of the black horizon, and damaged spots contribute to the above demands. The map shows clearly that man, with his crop and land management, initiates soil erosion. A big concentration of damage occurs in the barley fields of the valley. Cattle produce much less soil erosion in the woods and grassland.

4.1. Interpretation of the damage dimension classification

The map shows, that there exist large damage dimension differences in the upper Jinbar valley. An interpretation of these differences allows to emphasize two main statements:

1) The barley fields South of the Jinbar river show less soil erosion than the ones North of it. Reasons for such a conservation to the South, might be less rainfall intensity, or that the cultivation might be more recent than that to the North. These questions are now under study (in prep.).
2) Most of the areas damaged more than 20 % are exposed to the South or East. The affluents flowing from Gich to the Jinbar river, clearly show this tendency: West-exposed slopes do not show any severe damage, whereas most East-exposed slopes are extremely damaged. Soil erosion process studies showed a direct relation between the Eastern-exposed slopes and the rainstorm direction from Northeast (in prep.). Steeper slopes are generally more damaged than gentle ones. Ways and paths often initiate extreme damage on slopes by carrying concentrated water flows on them.

4.2. Interpretation of the depth of the black horizon

The average depth in the woods and grassland is 68 cm, varying with slope form and inclination. In the barley fields, some areas show a diminished depth, mainly on convex slope forms. Here, the depth class of 40–60 cm is much more common than in the woods and grassland. This must be explained as a result of sheet erosion.

4.3. Interpretation of damaged spots

The area South of the Jinbar river is less destroyed by soil erosion than the one North of it. Damaged spots of all stages can be found in this part of the barley fields. This enables us to give a morphogenetic idea of the development of soil erosion forms, which is:

1. Mixed soil horizons develop on convex spots by ploughing the reduced black horizon together with the brown one. Wind denudation and drying out of the soil are intensified.
2. Rainfall effects a washoff of the mixed soil to the bare rock, because little soil depth can not absorb a lot of water and the surface runoff increases proportionally.
3. The denuded rock remains without vegetation the whole year and soil erosion is effective all year long.
4. Accumulations arise where slope inclinations decrease on the foot of such destroyed spots.
5. When deep enough, secondary gullies carve the accumulations again.

Spots where the rock has been completely denuded by soil erosion, are mapped to scale in strong red colour. The map shows, that the density of all those spots alone would make it possible to do a sufficiently exact estimation of the damage dimension by soil erosion in any slope. On aerial photos, such denuded rocks can be made out fairly easily. It would therefore be possible to do a general review of soil erosion damages in Simen by aerial photo studies, mapping all the spots where the rock has completely been denuded. Such studies have not yet been done in Simen.

5. Soil conservation

This article shows that soil conservation is the only way for the Simen inhabitants to solve their soil erosion problems. If no steps are taken against soil erosion, the actual soil loss will lead to a catastrophic crop situation within the next few decades. The Simen people have already taken some soil conservation measures. With these actions they show that they recognize the problem of soil erosion and are fighting against it. Unfortunately, they have not yet developed effective techniques against soil erosion, but they are ready to accept any help from outside in order to improve their situation. The following chapters give a short list of measures already started by the Simen people and future possibilities for soil conservation measures.

5.1. Measures already started

Cutoff drains:
Surface run-off water is caught by horizontal or slightly inclined water ditches.
Bench terraces:
A few very simple bench terraces have been built in some parts of Simen.
Bushes:
Fields which can not be used for cultivation any more are left fallow. Hypericum bushes grow on the patches of soil and protect it against further erosion.

5.2. Some possibilities for conservation measures

The measures mentioned below are incomplete, they only serve as discussion points.
Cutoff drains:
If numerous enough, ditches may be effective on slopes below 11 % in inclination to catch the surface runoff.
Bench terracing:
Different kinds of bench terraces can stabilize slopes from 11 to about 56 % inclination. This would be a very labour-intensive method requiring work and financial assistance for a period of years.
Dams:
Within dams, gullies can be stopped from moving backwards into the soil.
Reafforestation:
Slopes with more than 56 % inclination should be reafforested with natural trees in conservation areas and with trees for domestic use outside the National Park.

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