UTF/ETH/037/ETH
Working Paper 2

ETHIOPIAN HIGHLANDS RECLAMATION STUDY

SOIL FORMATION RATES IN ETHIOPIA

(WITH SCALE 1:1 000 000)

by

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Preface

The Highlands of Ethiopia, lying above 1,500 m.a.s.l. and rising to peaks of over 4,000 m.a.s.l. contain what is probably one of the largest areas of ecological degradation in Africa, if not in the world. These areas are typified by deforestation, widespread erosion and severe depletion of soil on a very large scale. Hundreds of thousands of Highland inhabitants, and their predecessors, have devastated their environment to the extent that they are now living at barely subsistence level even in years of average rainfall. Effective conservation measures cannot be started without technical direction and incentives. As these are not available on a sufficient scale, the support capacity of much of the Highlands continues to decline.

Recognizing the severity, magnitude and complex nature of this degradation problem, the Government of Ethiopia (GOE) is funding, through a loan from the World Bank, an Ethiopian Highlands Reclamation Study (EHRS). The EHRS is being undertaken by a joint GOE/FAO Project (UTF/ETH/037) with 4 objectives:-

a. the formulation of proposals for a strategy for reclaiming the Highlands, in the light of an assessment of the extent and rate of degradation and an evaluation of experience in combatting degradation,

b. the identification of priority areas, policies and projects for implementing the proposed strategy,

c. the detailed preparation of at least two investment projects and

d. training Ethiopian officers in a), b), and c).

The EHRS, embodying these 4 objectives, is to be completed by March 1985

The first of the above mentioned objectives requires, amongst other things, an assessment of the rate at which degradation is taking place. Such an assessment has in principle to take into account both the rate of soil loss, the rate of soil formation and the rate of soil accumulation in the Highlands. The purpose of this working paper and its accompanying map is to provide tentative estimates of the varying rates of soil formation in the Highlands, employing a methodology developed by Dr. Hans Hurni, the author of this working paper.

Dr. Hurni is a well known geomorphologist with 9 years experience in working in conservation research in Ethiopia, currently as Manager of the Soil Conservation Research Project which is being funded and implemented by the University of Berne, Switzerland in association with the United Nations University, and the Soil and Water Conservation Department of the Ministry of Agriculture. The EHRS is fortunate in having secured, entirely without cost to the GOE/FAO project UTF/ETH/037, this significant contribution to our work programme from Dr. Hurni. The very substantial efforts which Dr. Hurni has made in preparing this working paper with its important map in the short time set aside for this purpose, that is September to November 1983, are very much appreciated and the project records its gratitude to Dr. Hurni and the Soil Conservation Research Project.

The purposes of EHRS working papers, of which this is No 2, is not only to contribute directly to the EHRS but also to generate feedback comments on the subject in question. It is hoped that such comments will themselves also contribute to the EHRS. Readers of this working paper are invited to contact Dr. Hurni by telephone 20-14-24 (Addis Ababa) or by post through P.O. Box 2597 Addis Ababa or through myself.

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Abstract

Soil formation rates are necessary to define soil loss tolerances, T, and the potential of the soil to regenerate and restitute once soil erosion and soil degradation is stopped. Soil formation rates do not include soil loss rates and/or soil accumulation rates which must be assessed individually.

In this Working Paper, a summary is given on the methodology of assessing and calculating soil formation rates for given environmental conditions in Ethiopia. Attached is a map, scale 1:1 million, giving soil formation rates in tons per hectare per year for the whole country.

Highest rates appear at altitudes around 2000 m.a.s.p. and in the West of the country, while highlands and lowlands have much lower rates of soil formation. Due to their high population and land degradation, the high mountains above 2500 m.a.s.l. will be most difficult to reclaim.

1. Introduction

The rate of soil degradation due to soil erosion can not be assessed with soil loss rates alone. It will be important to include two additional evaluations, namely the rates of soil accumulation resulting from upslope soil erosion, and the rate of soil formation as a natural process to build up the soil in situ.

In the framework of the Ethiopian Highland Reclamation Study, the Soil Conservation Research Project has taken the charge of providing the latter: A Soil Formation Rate Map at 1:1 million scale. A special methodology which did not exist so far was designed for this project by the author.

The explanatory notes given in this Working Paper are based on an empirical model to estimate annual soil formation rates of a given land unit in tons per hectare. The model itself is explained in Hurni (in prep.), and applied for the whole of Ethiopia with a map at 1:1 million scale, using basic data of the Land Use Planning and Regulatory Department of the Ministry of Agriculture, supplemented by own corrections for specific localities, and a thorough interpretation of the resulting soil formation rates on the basis of black and white as well as false colour landsat pictures at 1:1 million scale of the same Department.

Soil formation rates for the various land units of Ethiopia vary between less than 2, and more than 22 tons per hectare per year. This range is small compared with the range of soil erosion rates and accumulations from upslopes. However, soil formation rates will be very important to serve two purposes, namely (a) the evaluation of soil loss tolerances, i.e. the extent to which soil loss can be tolerated, and (b) the potential of soil regeneration once soil erosion can be stopped completely.

The map at 1:1 million scale will give a first broad survey of soil formation rates in Ethiopia. However, the same model can be used for any larger scales (up to 1:5,000), and also for refining the figures given on the 1:1 million map to locality specific conditions.

2. Soil Loss Tolerance and Soil Regeneration

Soil loss tolerance, T, is defined as the maximum amount of soil erosion that can occur without any reduction in crop productivity, which should be sustained indefinitely (Mannering, 1981:337).

In developing countries with traditional cultivation practices, it is unlikely that soils will be upgraded with technological means such as fertilizing, because this will be most probably uneconomic. Here in most cases, soil loss tolerances, T, can be assessed with the soil formation rates (Hurni, 1983). T may always be as high as the accumulations on the soil surface, and the decomposition rate of organic materials. However, if intensive weathering occurs within the soil profile, T may even be higher.

Since the soil formation rates given on the map represent the average of soil formation on the soil surface and within the profile, they can be directly used as soil loss tolerance rates, T. The higher the T values are, therefore, the easier it will be to reduce soil erosion rates to that required level. Implementation of soil conservation will accordingly be relatively more economic than in areas with low T values.

In some cases, it may be possible to completely stop soil erosion to zero. There, the soil formation figures given on the map can be used to determine the rate of soil regeneration with natural means alone. This especially applies to the map units with very low rates and degraded soils, where soil erosion must be stopped in order to allow a slow regeneration, and by this to increase the productivity of these soils with natural means. Highly degraded areas, therefore, can only be evaluated economically, if the soil formation rates are included in the various scenarios or models. Natural soil regeneration will usually be the cheapest, but also the slowest way of restitution and reclamation.

3. Summary of Methodology

An empirical model for the calculation of soil formation rates has been developed specifically for this project. So far, no methods for the quantitative assessment of soil formation rates existed. The model is based on a seven-step-methodology. In principle, the highest possible rate in the country was assessed, and related environmental parameters enabling this rate described. Then, each parameter was assessed as to how it might decrease the rate of formation for less favourable conditions, and bimodal relationships found for each parameter with soil formation. With these relationships, rates were calculated for different localities with respective environmental conditions. The seven steps of the methodology are summarized in the following sections.

In the first step, the maximum soil formation rate, F_m, of the tropical zone, in which Ethiopia is situated, was assessed for a specific locality where such an optimum was found (Sidamo Region, Welayta Awraja). It was found that in the optimum, a rate of 25 to 30 tons per hectare is possible.

In the second step, parameters influencing soil formation rates were enumerated, such as temperature, rainfall, rainfall varability and distribution, soil, soil depth, slope gradient, vegetation cover, etc. Of course, many of such parameters are interrelated and/or correlated to each other. The soil is itself the result of soil formation and soil degradation, but also contributes to soil formation through its soil water regime, organic matter content, genetic horizons, restrictive horizons, and many other relations and properties. Soil and soil depth are closely linked, but should also be separated since similar soil types may have different rooting depths and result in different formation rates. From the set of possible parameters contributing to soil formation, seven were rather incidentally selected, since they are available as basic data for the whole of Ethiopia. These are:

- Mean annual temperature, T_a : Formation factor $t = f(T_a)$
- Mean annual rainfall, R_a : $r = f(R_a)$
- Length of growing period, L: $l = f(L)$
- Soil unit, U: $u = f(U)$
- Soil depth, D: $d = f(D)$
- Slope gradient, S : $s = f(S)$
- Land Cover and Use, C : $c = f(C)$

Together with the maximum soil formation factor of the zone, $\cancel{F_m}$ $f_m = f(F_m)$, a total of 8 factors were used to calculate the soil formation rate of locality or, with average values, for a map unit. The equation should look as follows, soil formation, F, of a locality being the product of the 8 factors:

$$\boxed{F = f_m \cdot t \cdot r \cdot l \cdot u \cdot d \cdot s \cdot c}$$

In the third step, correlations between single factors and soil formation were empirically drawn, based on soil formation studies (Jenny, 1980; Hall et al, 1979; Hurni, 1983, see Hurni, in (prep.). f_m received the value 24 t/ha/yr for the tropical zone.

All other factors would receive values between 1 and 1.1 for optimum conditions, and decreasing values for less favourable conditions. Thus, optimum temperatures would be between 17.5°C and 22.5° mean annual temperature and obtain the factor 1; optium rainfall over 1950 mm per year (=1) ; optimum length of growing period over 270 days per year (=1); optimum soil units Fluvisols,Chernozems . Acrisols, Nitosols, Ferralsols, Vertisols; (for best phases having the value 1.05) optimum soil depths more than 100cm (=1); optimum slope gradients less than 10% (=1); and optimum land cover intensive cultivation (this last condition receiving in value 1.1). Mean annual soil formation rate, F, as the product of all 8 factors:

$$F = f_m \cdot t \cdot r \cdot l \cdot u \cdot d \cdot s \cdot c$$

will in the best case be

$$F_{max} = 24 \cdot 1 \cdot 1 \cdot 1 \cdot 1.05 \cdot 1 \cdot 1 \cdot 1.1$$
$$24 \cdot 1.155$$

F_{max} = 27.5 t/ha/yr, corresponding to the maximum soil formation rate found in Ethiopia under optimum conditions.

In the fourth step, the empirical model was tested for different soil formation rates in Ethiopia known to the author, such as the Simen highlands, the Wello mountains, the Harerge mountains, in order to see whether modelled rates came close the actual ones.

In the fifth step, a grid system of 1200 points was laid over Ethiopia (every 25km or 15' one spot), and basic data of the seven parameters were collected using information and sources of the Land Use Planning and Regulatory Department of MOA. Using the functions drawn up in the third step, the factors of t,r,l,u,d,s,c were calculated for each point (about 8000 data), and all multiplied with f_m = 24 and with each other. This resulted in 1200 soil formation rates in the grid over Ethiopia. Obviously wrong rates were traced down and the error was mainly found in unprecise basic data which had to be corrected. Field experience and knowledge of localities in all 14 regions helped to detect obvious inconsistencies.

In the sixth step, the rates were put on black and white as well as false colour satellite imagery of the LUPRD, and isolines of similar rates drawn using the following principles (in the order of their importance):

1. Geomorphology (Similar units: Isolines along geomorphic boundaries)
2. Soils (Similar units: Isolines along boundaries)
3. Altitudinal belts: (Similar units : Isolines along boundaries)
4. Vegetational Limits (False colour interpretation)

Again, field experience was very useful and indispensable for drawing the isolines.

In the seveneth step of the methodology, the map will be taken to the field and checked a second time for feasibility. This might result in further corrections of the map.

4. Interpretation of the Map

The map "Soil Formation Rates, Ethiopia, 1:1 million Scale" shows isolines of similar rates, namely 2,6,10,14,18, and 22 tons per hectare per year. Units between the isolines will therefore present average soil formation ranges of:

<2
2-6
6-10
10-14
14-18
18-22
>22

Tons per hectare per year (one ton being approximately 0.12 mm soil depth)

It must be kept in mind that the formation figures do not include soil loss rates and/or soil accumulation rates. These must be assessed individually to obtain soil degradation rates, restitution rates, or ecosystem stability, vulnerability and instability with the soil degradation ratio (cf Hurni, 1983)

Looking at the country as a whole, certain tendencies can easily be made out for soil formation rates, namely a zonal varability, an altitudinal varability, and a local variability.

Zonal Variability

From North to South, soil formation rates clearly increase, and finally decrease again: North of Asmera, rates are generally below 2 tons per hectare annually. South of Asmera, 2-6 t/ha/yr are common. Around Gonder, 6-10 t/ha/yr dominate, and around Gojam 10-14 t/ha/yr. In Welega and Kefa, 14-18 t/ha/yr give highest average rates, dropping to 10-14 t/ha/yr in some parts of Gemo Gofa, finally decreasing to 6-10 t/ha/yr and to less than 2 t/ha/yr towards the Kenyan border.

From West to East, soil formation rates are low in Gambela (6-10 t/ha/yr) quickly increase to 18-22 t/ha/yr in Kefa and Welega, decrease to 14-18 t/ha/yr in Southern Shewa and to 6-10 t/ha/yr in the Rift Valley, increase again to 10-14 t/ha/yr in Arsi region, and finally decrease to 6-10 t/ha/yr in the Harerge Highlands. The zonal variabilities are primarily the result of rainfall and temperature variances, while other parameters are minor contributors.

Altitudinal Variability:

In the figure below, average soil formation rates have been correlated with altitudes for various cross-sections in Ethiopia, one in the North (Gonder), one in the West (Welega), one in the South (Gamu Gofa), and one in the East (Shewa).

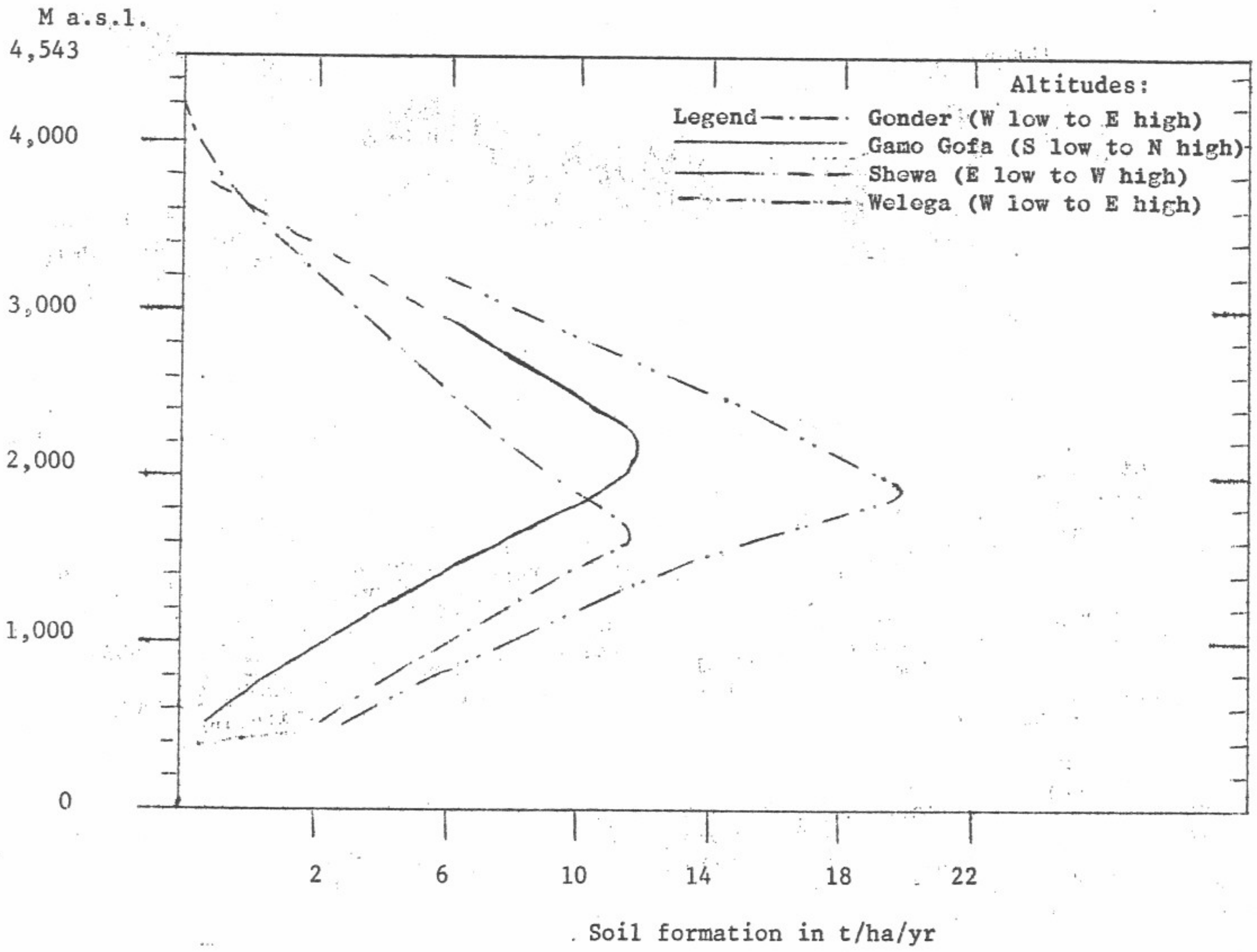

Figure: Correlation of soil formation with altitude for different cross-sections in Ethiopia.

Due to rainfall and temperature regimes, highest rates are generally found between 1600 and 2200 m.a.s.l. for all cross-sections. These altitudes have mean annua temperatures between 17.5 and 22.5°C and sufficient rainfall to optimize soil formation. In the lower altitudes, Gonder and Welega have higher rates than Gomu Gofa and Shewa, due to the moist climate along the border to Sudan. Highest rates, are seen for Welega (Kefa, Ilubabor) because of their humidity. In addition to optimum mean annual temperatures and high annual rainfall, soil, slope and land cover parameters are very favourable. Above 3200m however, all cross-sections have again similar rates, quickly decreasing towards the climatic vegetation limit at about 4000 to 4400 m.a.s.l. due to decreasing mean annual temperatures (0°C at about 4200 m.a.s.l).

In the deep valleys of Tekeze, Abbay, Omo-Gibe, therefore, soil formation rates rapidly drop to very low figures, due to the mainly semi-arid conditions, even if the surrounding highlands have high rates,

Local Variability

It must be kept in mind that the soil formation rates given on the 1:1 million map represent average conditions. Actual rates may considerably deviate from those averages, due to locality specific (edaphic) factors, like soil, soil depth, slope gradient, and land cover.

For more detailed analysis at larger scales, however, it is possible to adjust the rates given on the map according to the system described in Hurni (in prep.).

5. Conclusions

To know soil formation rates of a given locality is an important tool to assess net soil degradation rates and soil degradation ratios and to evaluate the rate and feasibility of soil regeneration after conservation. It also provides soil loss tolerance figures T which are needed for soil conservation design.

The map, scale 1:1 million, presented in this Working Paper gives isolines of similar soil formation rates, ranging from 2 to 22 tons per hectare per year for the whole of Ethiopia. Tendencies in soil formation rates are clearly emerging, showing that the potential for soil regeneration is rather high at medium altitudes between 1600m & 2200m asl, but low for higher and lower altitudes. Furthermore, the Northern regions have a much lower potential for reclamation and soil resitution than the Western and Southern regions.

In summary, the densely populated high mountain areas, especially in the North, have the most fragile ecosystems, where damages are extremely high and can be reclaimed and restored only very slowly. The lowland areas, on the other hand, which have only little population and slight degradation,will also be difficult to reclaim, once degradation will have taken place, since soil formation rates are generally refers to settlements and development projects in semi-arid and lowland areas which will need conservation from the very beginning of implementation, not to repeat the mistakes of the highlands.

Annex 1

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