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An ecosystem approach to soil conservation

Hans Hurni

A variety of reasons explain the worldwide acceleration of soil degradation (*16*) and the general lack of sufficient action to halt the disastrous situations. The key mechanisms of soil erosion are relatively clear—population growth, deforestation, and the resulting changes in land use (*13*). Much research has been carried out to understand the processes of soil erosion and to find technological solutions.

However, field technicians know that technical solutions alone are not sufficient and that there is no single remedy for the treatment of watersheds. Most discouraging is the failure of most conservation programs and land use plans to spread from a pilot project area to its surrounding area. In the rare successful projects, success mostly comes through detecting and by-passing bottlenecks—hindrances to conservation progress. Most bottlenecks exist in the human element of a land use system (*7*). Only a holistic approach can unearth these bottlenecks and lead to interdisciplinary watershed development schemes that remove them.

This paper presents a systematic guide for detecting bottlenecks to soil conservation. The approach was developed from findings of the recently launched UNESCO Man and the Biosphere (MAB) programs. In a worldwide network and a series of programs, ecosystem research emphasizes the importance of the human component (*3*).

A geoecosystem approach to soil conservation

A geoecosystem is a selected land area classified into three subsystems: nature, land use, and man. These are interrelated and also related to elements outside the area. Figure 1 is an example of a regional economic-ecological system representing an open geoecosystem in the Swiss MAB projects (*15*). In figure 2, the scheme of figure 1 is modified for the soil erosion and conservation complexes within a geoecosystem. The boundaries of a selected area should follow a watershed, because hydrologic cycles are of paramount importance for conservation issues. If bottlenecks appear during implementation of soil conservation plans, the key words in figure 2 can be used as a checklist for evaluating single parameters. Qualitative or intuitive assessments or individual experience should be complemented by research only where it is important for problem solving. Most conclusive is the evaluation of relations between the subsystems and key words, such as the influence of a land use on gullying or the constraint of labor input in soil conservation in relation to the socioeconomic situation of a farmer.

Not all parameters need to be assessed in each case; personal intuition should be used to set priorities that are felt to contain the bottlenecks and then to study their relationship with other parameters.

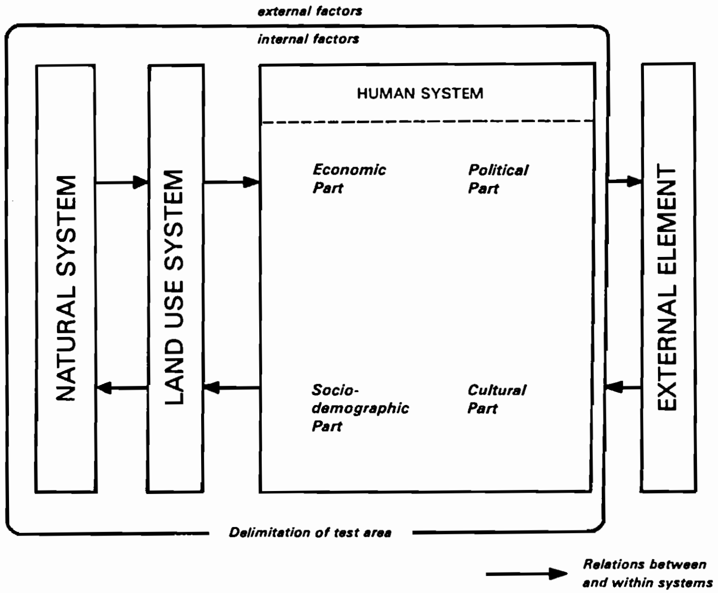

Figure 1. Regional economic-ecological system representing an open geoecosystem.

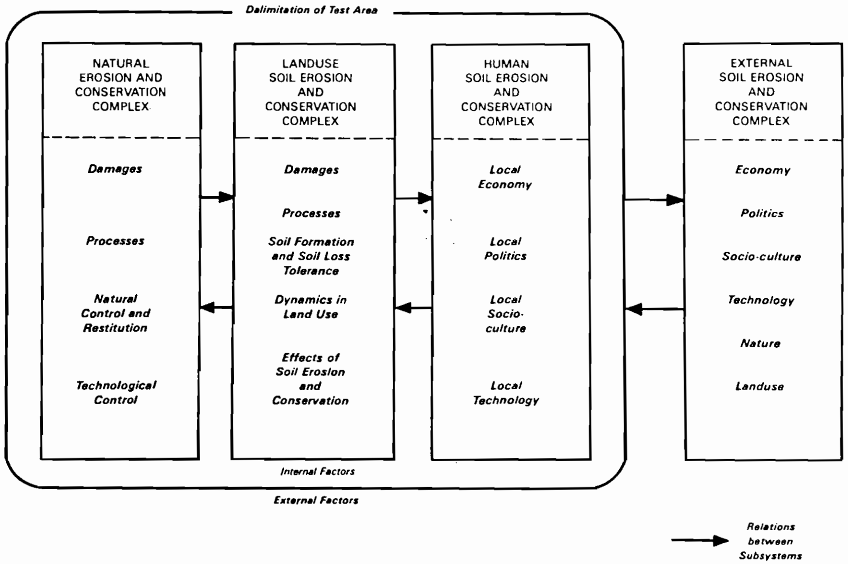

Figure 2. The soil erosion-soil conservation complex in a geoecosystem is a framework for detecting bottlenecks in soil conservation.

The natural complex. One essential for the study of man-caused soil erosion is the evalution of the natural erosion that would occur without human interference. Natural processes are more difficult to control and often almost impossible to separate from man-made processes, but four major factors should be assessed (Figure 2):

Damages: Natural erosion damages (gullies, accumulations, sheet erosion); natural soils and vegetation (past and present).

Processes: Reconstruction of past processes before human interference (with damages) including parameters of climate, relief, vegetation, soils, and time.

Natural control and restitution: Potential for natural control; soil formation rates on present soils; potential for revegetation and reforestation.

Technological control: Feasibility for engineering measures and their ecological and economical consequences.

The land use complex. This complex may contain many bottlenecks.

Damages: Assessment of soil erosion damages (to soils and vegetation) and consequences (for harvest yields).

Processes: Assessment through estimations, measurements, and modeling that consider factors of time, cultivation practice, land management, relief, soil, and climate.

Soil formation and soil loss tolerance: Rates of soil formation and accumulation and of soil development through management, using estimations or indirect approaches (*12*).

Dynamics in land use: Age of traditional systems, changes in past and future, future land requirements, possible conflicts in land use, land and soil resources.

Effects of soil erosion and conservation: Soil removals, deposits, and movements in relation to harvest yields, land use intensifications, and other economic considerations.

The human complex. This complex is the most difficult to assess and understand. Long-term experience or intuition, or both, may be required to find the bottlenecks.

Local economy: Cost-benefit analysis for soil conservation measures (including ecological and long-term benefits within the geoecosystem).

Local politics: Dynamics and implications of possible changes through soil conservation: land tenure, reallocation, legislative problems, decision-making processes, field implementaton, perception of groups of farmers.

Local socioculture: Present status and future demographic trends; movements; social organization; inertia and traditions; perception of innovations; ethics, mores, and religions; personal perception of soil conservation.

Local technology: Present and future availability of conservation measures, materials (plant seedlings, stone, machinery, tools), local labor for conservation works, and administrative and technical network.

The external complex. Many external factors can influence the geoecosystem.

Economy: Cost-benefit analysis at a wider scale: necessary external input of financial or material resources for a successful implementation (funds, refunding options).

Politics: Wider political effects of implemented measures and their positive or negative feedbacks. Consequences at external scale: political consolidation or unrest; long-term prospects or problems.

Socioculture: Similar factors as for local socioculture, applied at wider scale; add educational and environmental considerations.

Technology: Similar factors as for local technology, applied at wider scale; add schooling, functional, and environmental education.

Nature: Interactive erosion-sedimentation processes with areas outside the geoecosystem: highland-lowland interactions, sedimentation, acceleration of natural, and man-caused soil erosion.

Land use: Overlapping land use connections important in soil conservation: cattle movements, migration of people, external land use interests.

Relations between the complexes. The natural, land use, human, and external complexes have relations that can act as bottlenecks to soil conservation. All possible relations between the listed key words have to be considered. The human components within and outside the geoecosystem may be much more important than the land use and natural processes.

Figure 3. Traditional Ethiopian cultivation of cereals and pulses with ox-plow on steep slopes in Wello region. This peasant, by seeding peas directly on the grass fallow, and applying only one plowing, can keep soil losses down to 35 t/ha per year, one-third of normal rates. H. Hurni, June 1981.

Three case studies demonstrate the application of the geoecosystem approach in developing countries.

Case study 1: The Ethiopian highlands

Nature. The Ethiopian highlands range in elevation from 1,500 to 4,550 m above sea level. They have very high agricultural potential: generally sufficient rainfall (500 to 2,400 mm annually), temperatures allowing the cultivation of many types of crops (up to 3,700 m above sea level for barley), naturally well developed soils, and a relief of undulating highland plains and rolling hills amid steep escarpments and deeply incised valleys.

Natural erosion in the highlands is limited to linear erosion by the rivers and some gullying along recent tectonic movements of the Rift valley system.

Land use. Agriculture covers most of the highlands and adjacent lowlands. Forests have been reduced from 40 percent before human occupation to 2.8 percent. Land use in the highlands consists of mixed livestock and cereal production in the north and east and horticultural crops in the southwest (*19*).

Soil erosion damages are extremely high in the northern and eastern high mountain areas, along all highland escarpments, and in deep valleys. Damages, in the form of gullying, are also widespread along the Rift valley system (Figure 3).

Since 1981, soil erosion processes have been measured in four agroecological zones in small watersheds and by test plots (*8, 9*). The test plots are on traditionally cultivated fields of different gradients, 15 m long and 2 m wide. Table 1 shows the average annual soil loss of a cultivated field (cereals, pulses) as measured by the test plots, and modeled by the universal soil loss equation (USLE) (*20*) adapted for steep slopes by a modified S factor (*10*).

Man. In the past, highland peasants took little action to reduce erosion. In the past 5 years, however, the World Food Programme (WFP) and other agencies intensified activities in soil conservation (Figure 4) with over $250 million (U.S. dollars) invested by the end of 1984. The urgency of soil conservation has not been well perceived even in areas of the worst soil degradation and yield reduction. The WFP projects often have difficulties in persuading farmers through the Ministry of Agriculture.

Relations. Population growth only recently forced peasants to cultivate steeper slopes. Erosion on slopes up to 30 percent and 30 m in length was relatively low (below 100 t/ha per year), if one considers soil accumulations from upslope and natural soil formation rates. Within a generation of 20 to 30 years, a peasant will not perceive a major reduction of soil depth on his fields. Consequently, he does not regard soil erosion as a life-threatening problem. Recent studies show that centuries of traditional land use systems passed before the soils in northern Ethiopia were completely degraded (*1, 11*).

Table 1. Predicted mean annual soil losses from a traditional Ethiopian cultivated field.

Slope Length (m)	*Mean Annual Soil Loss by Slope Percentage*						
	10	*20*	*30*	*40*	*50*	*60*	*70*
	t/ha						
10	12	35	54	61	68	74	81
20	16	50	76	86	95	105	115
30	20	62	92	104	115	127	138
40	24	70	108	122	134	148	162
50	26	78	119	135	148	164	179

Figure 4. Results of the extensive soil conservation campaign in Ethiopia funded by the World Food Programme. Small terraces were constructed for reforestation and contour bunds for plowed land that should develop into graded terraces in the course of decades. M. Coendet, Harerge region, March 1982.

Bottlenecks. From consideration of the factors in figure 2, the following bottlenecks became apparent:

1. Local peasants have a low perception of the soil erosion problem despite accelerating rates in the recent past on steeper slopes. This bottleneck should become a central target of the soil conservation campaign and be tackled by an intensified educational campaign.
2. Present damages have left such shallow soils that terracing of steeper and convex slopes is no longer feasible.
3. Local technology for contour bunding and terrace development is not widespread because of the lack of training.

These data and analyses are being evaluated in the Soil Conservation Research Project of the University of Berne, Switzerland, in association with the United Nations University (UNU), Tokyo, Japan, working since 1981 in cooperation with the Ethiopian Ministry of Agriculture.

Case study 2: The Nepalese middle mountains

Nature. The Kakani area, about 10 km northwest of Kathmandu, is typical of Nepal's middle mountains. It is situated between 1,000 to 2,000 m above sea level. Rainfall is concentrated in the main monsoon months, June to August. Relief is extremely steep, with 50 percent average gradients. Geological basement is deeply weathered, but erosion under natural vegetation is low except for a few landslides.

Land use. Unlike the Ethiopian highlanders, the inhabitants of the Kakani area have developed a refined system of terraces that have transformed nearly all the landscape except for government forest reserves (Figure 5). Six land uses are distinguished: two types of terracing (irrigated-flat and rainfed-graded), untilled land, grazing land, forest, and settlements (*14*).

Soil erosion occurs on graded terraces, untilled land, grazing land, and in settlements. Annual soil loss from graded terraces has been estimated with the USLE at about 200 t/ha (5), but K and P values probably were overestimated by a factor of about 2. A more realistic estimate would be 50 t/ha from a terraced slope with rainfed cultivation.

The more dangerous mountain hazards—landslides and gullies—cover only about 1 percent of the Kakani area. From landsliding alone, annual sediment loss has been calculated at 12,000 m^3/km^2 (2). This figure is misleading, however, since it averages the 1 percent areal cover of landslides over the remaining 99 percent of the area. Together with sheet erosion from terraces and from untilled and grazing land, 170 t/ha per year seems to be a realistic estimate of soil loss. In many instances, landslides on cultivated land are repaired and brought back into cultivation (*14*).

Figure 5. Harmonious terraces around Khagatigaun village in Kakani, Nepal, nearly hide landslides and gullies, which contribute to very high annual sediment yields that damage downstream areas. H. Hurni, November 1979.

Man. The Kakani area is inhabited by ethnic groups and castes that do not interact much. A peasant generally protects only his own land and only the parts considered most rewarding. He neglects less fertile land and does not consider the consequences on fields downslope.

Relations. An analysis of the Nepalese middle mountain situation using figure 2 results in the following reflections:

1. Controls for soil erosion in the Kakani area have been excellently included in the traditional terracing system, so that only 1 percent of the area has catastrophic levels of erosion.
2. Under the present circumstances, soil erosion processes in the land use system are adequately controlled through soil conservation and are tolerable because of the deeply weathered bedrock.
3. However, the Kakani geoecosystem is an open system, where highland-lowland interactions through runoff are predominant because most of the sediment yield leaves the watershed and causes serious damage to the Indian footplains. From this point of view, even the 1-percent damaged area in Kakani has to be conserved.

Bottlenecks. Several bottlenecks block conservation progress in the Kakani area.

1. The main bottleneck for the control of landslide-gullying is the lack of cooperation among ethnic groups of the area. Irrigation channels for wet terraces need cooperative networks to prevent overflowing and gullying. Also, the disregard of downstream effects is almost impossible to eliminate, except through intergovernmental actions (inputs from outside into the geoecosystem).
2. Common-owned land receives low interest for conservation, but its high runoff rates disturb terraces downslope.
3. Natural erosion rates due to relief are almost uncontrollable.

These reflections are based on results of the Mountain Hazards Mapping Project of UNU and UNESCO-MAB Nepal, where the University of Berne is participating under the leadership of Dr. Hans Kienholz.

Case study 3: The northern Thai mountains

Nature. The northern Thai mountains, between 500 and 2,500 m in elevation, formerly were covered by tropical forests. Rainfall is 1,000 to 2,500 mm per year and is concentrated in the months July to September. Almost all natural erosion occurs along the rivers.

Land use. Shifting or swiddening agriculture is the major land use system with different traditions according to the ethnic groups of highland people (*10*).

About 75 percent of Huai Thung Choa, an area typical for the mountains in northern Thailand, is still covered by secondary forests in different regrowth stages. Imperata grassland, as the result of annual burning, covers nearly all mountain tops (20%). The remaining area (5%) is cultivated swidden fields, irrigated terrace fields, and villages. Soil loss rates are highest on the swiddens (Table 2).

In contrast to both Nepal and Ethiopia, the soils at Huai Thung Choa are shallow and topsoils are exhausted within a few years of cultivation. For this reason, traditional farming systems use long fallow periods between cultivation periods.

Man. Highland groups have developed different conservation land use systems. Lisu highlanders cultivate a swidden field with maize followed by opium poppies for 3 to 6 years (Figure 6), then abandon the field permanently so that a fallow period of several decades is possible. Karen highlanders cultivate a swidden for one year only, then leave it fallow for 5 to 20 years before recultivation. In both systems, soil formation during fallowing can offset soil loss during cultivation (*12*).

Despite ecological land use systems, the northern Thai mountains—like all tropical rainforests—suffer from serious deforestation and soil degradation.

Relations. Analysis of the geoecosystem according to figure 2 found the following constraints:

1. The northern Thai mountains have undergone extensive in-migrations from the plains and from other mountains in the "Golden Triangle" (*18*). This brought an intensification of land use systems because of scarcity of suitable land for swiddening. Lisu cultivate a field longer now than before; Karen return earlier to a swidden for recultivation (*6*).

Table 2. Predicted mean annual soil losses from a traditional northern Thailand maize-opium swidden (*10*).

Slope Length (m)	*Mean Annual Soil Loss by Slope Percentage*						
	10	*20*	*30*	*40*	*50*	*60*	*70*
				t/ha			
10	19	56	87	98	108	119	130
20	26	79	122	138	152	168	183
30	32	98	148	167	184	203	222
40	38	113	173	195	215	237	260
50	42	125	191	216	237	262	286

Figure 6. A Lisu highlander with his poppy swidden in Huai Thung Choa area, northern Thailand. Annual soil losses from this field amounted to 150 to 300 t/ha (*10*) and will require 80 to 100 years of regeneration under secondary forest after several years of cultivation. H. Hurni, November 1979.

2. Shortening the fallow period prevents sufficient soil formation. The soils are subject to long-term degradation that prevents even the secondary forests from recovering quickly.

Bottlenecks. In general, in-migrations and increases in the indigenous population lead to a massive change of the traditional land use systems with catastrophic consequences for the soils and vegetation. Since this increase can not be halted, alternative agricultural systems have to be developed and adopted to improve the land-consuming, shifting cultivation systems.

Agroforestry trials on swiddens, started in 1980, reduced soil erosion to about one-fifth of traditional rates, thus allowing a considerable shortening of fallow periods, and increasing the production potential of the area (*17*). Much extension work, however, is needed to promote and introduce such alternatives adapted to the traditional systems (*10*), and additional bottlenecks may appear in the course of this work.

The Huai Thung Choa case study is part of the UNU - Chiang Mai

University Project for Agroforestry and Highland-Lowland Interactive Systems, for which the University of Berne has evaluated soil erosion and designed soil conservation research through the Soil Conservation Research Project.

Conclusion

Soil conservation is needed worldwide, but bottlenecks are preventing successful implementation in many cases. Detecting the bottlenecks is an important basis for the promotion of soil conservation.

Through an integrated, geoecosystem approach (Figure 2), the factors and relations revealing bottlenecks in soil conservation can be assessed qualitatively, sometimes subjectively or quantitatively. The approach can also be used to find methods of by-passing individual problems.

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