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Sustainable Land Management – A New Approach to Soil and Water Conservation in Ethiopia

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University of Bern, Switzerland

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Foreword

Through centuries of farming practices the farmers and pastoralists in Ethiopia were managing their land resources pertaining to the needs of prevalent populations. With an increasing population and growing demands more land was put under cultivation. Subsequently forest areas were cleared, encroaching agriculture into steep slopes and areas that were not suitable for agricultural activities. Land degradation and particularly soil erosion by water not only reduced the productivity of the land but also aggravated the effects of drought, such as famine and migration. Obvious signs of degradation in the highlands of Ethiopia are wide gullies swallowing fertile lands and rock-out crops making farming a risky business. But also less visible sheet erosion processes result in a tremendous loss of fertile topsoil, particularly on cropland.

Efforts have been made by the farming communities to mitigate land degradation by developing local practices of conserving soil and water. With keen interest and openness one can observe such indigenous practices in all corners of Ethiopia. Notwithstanding these practices, there were also efforts to introduce other soil and water conservation interventions to control erosion and retain the eroded soils. Since the early 1980s numerous campaigns were carried out to build terraces in farmlands and sloppy areas. Major emphasis was given to structural technologies rather than on vegetative measures. Currently the landscape of the northern highlands is dotted with millions of hectares of terraced fields and in some places with planned watershed management interventions. Apparently these interventions were introduced without prior investigating the detailed problems and conservation needs of the local population.

Training in soil and water conservation was provided by some of the higher education institutions but since it was not based on studies of the problem in the country it hence lacked relevance. In teaching aspects of sustainable land management at Mekelle University, we were always challenged by our students on why we lack references to the Ethiopian situation. Although the Ethiopian Soil Conservation Research Program (SCRP) was initiated in 1981, its studies, experiences and data were not adequately used in higher education until recently. Realizing students' needs, an optional course on New Approaches to Sustainable Land Management was introduced to senior students. Training modules were developed to a large extent based on studies and data of the SCRP. Its research contributed to understanding the problem of soil erosion and the technical and scientific merit of the interventions. After testing the material for four semesters and based on critical evaluations by students and staff, the course was recommended as a requirement and suggested the development of a textbook. The required course was offered for further three years both at undergraduate and postgraduate levels and the training material is now compiled in this textbook. It is the first endeavor for Mekelle University to utilize existing

databases for compiling a textbook. The text will be a tool for bringing issues of land management into debate and act as a reading material for further elaboration and development. The suggestions and points of discussion raised by our students were highly appreciated and incorporated in this book.

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Mekelle and Bern, March 2006

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1 Approaches and Concepts

1.1 Introduction

Sustainable land management (SLM) has emerged as an issue of major international concern. This is not only because of the increasing population pressure on limited land resources, demanding for increased food production, but also by the recognition of the fact that the degradation of land and water resources is accelerating rapidly in many countries in general and Ethiopia in particular. It is also becoming clear that the limits to lands, which are suitable for agriculture, are now being reached. If the lands, which are moderately or well suited for agriculture, are currently in use, then it follows that further increases in production, to meet the food demands of rising populations, must come about by the more intensive use of existing agricultural lands. To combat the often cited deleterious effects of intensification, particularly with regard to environmental effects requires the development and implementation of technologies and policies, which will result in sustainable land management (Gisladottir and Stocking, 2005; Campbell and Hagmann, 2003).

The growing interest in the concept of sustainability was given added stimulus at the United Nations Conference on Environment and Development (UNCED), held in Rio de Janeiro in June 1992. Agenda 21, a major action plan developed at UNCED, focused attention on the need to make development more economically and environmentally sustainable, and socially acceptable. Chapter 10 of Agenda 21 is concerned with the planning and management of land resources. For these reasons sustainable land management is now receiving considerable attention from development experts, policy makers, researchers and educators.

Understanding the soil resources is central to sound soil and land management. In this regard knowledge of the nature and properties of soils is vital in regions where soil productivity is often limited by poor soil fertility and where the need for food production is large (Lal, 2004; Sanchez, 2002). In addition to the low soil fertility, soil degradation is an increasing threat in many parts of Ethiopia (Nyssen et. al., 2003a; Hurni, 2000). There is an urgent need to understand the processes involved so that remedial actions can be put in place with a view to achieving sustainable land management.

In an attempt to address the issues of SLM within the agriculture and natural resources management training offered in Ethiopia, an innovative course “A New Approach to Sustainable Land Management” is developed taking into consideration the availability of research outputs mainly from the Soil Conservation Research Program (SCRP) and other institutes operating in Ethiopia. This course is offered by the Department of Land

Resources Management and Environmental Protection (LaRMEP) for undergraduate and post-graduate students majoring in Soil and Water Conservation and Dry Land Forestry and Environmental Protection, and Tropical Land Resources Management respectively.

One important basis for the book at hand is the SCRP database (Soil Conservation Research Programme). The database is one of the major results of 17 years of research in soil and water conservation in the Ethiopian Highlands. The SCRP database is to date the most comprehensive long-term monitoring database on soil and water conservation in Ethiopia.

The SCRP was introduced in 1992, funded by the Swiss Agency for Cooperation and Development (SDC). Program design, coordination and management were the shared responsibility of the Institute of Geography, University of Bern, Switzerland (now Centre for Development and Environment, CDE) and the Ministry of Agriculture in Ethiopia. Although the SCRP phased out in June 1998, a lot of valuable long-term results have remained available. The data and experience of the SCRP provide many lessons to be learned, which will be of considerable help for improving future programs on similar topics (Soil and Water Conservation). In the 13 chapters of this book, the experience of 17 years of research is capitalized and used to introduce and explain different topics such as agro-ecological zonation, monitoring, database analysis, data management, decision support systems, etc.

1.2 Elements of the new approach

Sustainable Land Management as a new approach considers lessons learnt from research on soil and water conservation undertaken in the country representing diverse agro-ecologies, focuses on a compromise between top-down and bottom-up approaches and requires a high methodological flexibility:

- Addressing complex societal problems requires a transdisciplinary approach, i.e. involving different science disciplines, scientific and non-scientific actors, and integrating their knowledge systems in a process of societal learning (Hurni and Wiesmann, 2002). Transdisciplinarity (Yakob et al., 2004) requires true participation. Recognizing the problem is a key issue in natural resources management research. Many organizations are still highly compartmentalized and hence the transdisciplinary work is poor. Others have multi-disciplinary teams in which the different disciplines are present but do their own business rather than truly integrate. Given complexities and multiple disciplines, do we have scientists who see “the whole” or just only look into narrow disciplinary discourse to solve multifaceted problems related to sustainable land management? Do we have enough synthesizers such as ecologists or geographers? It will be essential for transdisciplinary teamwork that the integration domain is at an appropriate level. To ensure this, selecting of some hypotheses at a broader outcome or impact level that ultimately depend on integration for the individuals` and team's success is essential (Hurni et al., 2004).

- We need fewer standards, more variety and creativity to adapt – not adopt! – measures to real life situations. Aspects to consider specifically in integrated natural resources management interventions, such as in soil and water conservation are: integrating technologies, institutions and policies at implementation; establishing processes for improved and more straightforward adaptation of technological knowledge; increasing the testing of technologies in the production context (i.e. in the market and policy context); and increasing the use of visualization, mapping and simulation tools to link research to farmers (Fikru et al., 2005; Campbell and Hagmann, 2003).
- Such an approach requires rethinking of the roles of research, extension, land users, decision-makers and different stakeholders. Successful soil and water conservation interventions as part of integrated natural resources use to achieve sustainable land management need to manage communication at different levels. Particularly important is the communication at the farmer-extension and farmer-researcher interfaces along the anticipated impact pathways, right from the beginning of the intervention. Researchers engaged in integrated resource management assume the responsibility to ensure the appropriate communication media for different clients and partners. Communication with donors and local media etc. are also important if a critical mass is to be achieved (Campbell and Hagmann, 2003). In most cases a well-intentioned and better-implemented intervention might be unnoticed by the external communities and stakeholders for lack of publicity and the provision of transparent information in a timely and predictable manner. (Mitiku et al., 2001). According to Campbell and Hagmann (2003) from the beginning of projects, steps need to be taken to: ensure documentation of the process and methodology; devise innovative ways of sharing; distill simple messages in local languages for use in appropriate media; draw lessons from past assessments of the effectiveness of different media; and instill stories for donors and the policy makers alike (Mitiku, 2000).
- A shared problem and opportunity-driven focus are essential: the key to success of any multi-stakeholder action is a shared understanding and perception of the problem and/or the opportunity (Stillhardt and Frey, 2001; Ludi et. al., 2000, 1998; CDE, 1998). Agreements need to be negotiated until all key players have the same understanding with regard to interventions in sustainable land management. From a study made in the Amhara region (Ludi et al., 2000, 1998) specific aspects of integrated resource management were considered before implementation of the sustainable land management pilot project. These included among others:
    - Negotiating goals and visions among stakeholders;
    - Establishing a negotiated action plan among stakeholders;
    - Ensuring an appropriate and early baseline diagnosis, to assess constraints and opportunities, and to identify research needs;

- Understanding of how people organize and participate;
- Articulating the need and demands of stakeholders;
- Devising better tools to prioritize problems, in a manner acceptable to all partners;
- Facilitating understanding of the spatial extent of problems;
- Ensuring exposure to opportunities.

The approach considers a situation where agricultural and natural resource management advisors, who work in a team, make decisions on the basis of reduced information, with limited knowledge of the local situation, under time pressure, and present opinion to an audience.

The examples and exercises will try to depict real-life situations so that the students will be able to work in groups in a time limited class work with limited information (tables, graphs, maps, photographs, transparencies, slides etc.) at their disposal for a local appraisal of a situation. This exercise simulates the frequent situation of incomplete data sets (in a real-life situation in Ethiopia obtaining complete data set for decision support system is scanty, patchy and dispersed in several sectoral institutes). The results of the exercises (or information given) do not lead the students into only one clear direction. Subjective and consultative decisions are needed in terms of role-play, methods from PRA (Participatory Rural Appraisal), SDA (Sustainable Development Appraisal), PTD (Participatory Technology Development), etc. Since all concerned stakeholders do not see the same problems with the same intensity and priority, village profiling, stakeholder analysis and discussion, and participative approaches are emphasized. In most cases students may be required to defend unpopular decisions during their exercises and convince others during the presentation of the group work, openly discuss on results of their findings, and accept and forward constructive critics and participate in system analysis.

The goals of the approach are to equip the students with appropriate framework knowledge of the issues of sustainability with regard to land management. After reading the text the student will be able to understand the extent of land degradation in the major agro-ecological zones of Ethiopia, design vegetative, agronomic and structural measures to reverse degradation, undertake applied research in land management and train others in sustainable land management at different levels (extension agents, subject matter specialists, and farmers).

It is assumed that the student is previously exposed to several land resources courses as a basis for this approach. In this sense, this document is intended as a reading material for students taking the course on “New Approaches to Sustainable Land Management”. At the end of the course they will have an overview of land and soil degradation, as well as starting points for decision making for more sustainable land management by developing "structural" knowledge (network thinking) of important thematic elements and their interrelations. This will enable them to gain practical knowledge (not only scientific knowledge) relevant for decision making i.e. they would know indicators of unsustainable land management, evaluate the importance of land problems (soil degradation) for instance on where and when degradation processes occur, what possible causes and consequences are operating, know the possible starting points for soil and water conservation and agro-forestry measures, know selected sustainable land management technologies and, more importantly, the principles of their functioning. They are able to critically evaluate potentials and limitations of a local setting, including bio-physical, social, cultural, economic and indigenous approaches in order to develop situation-specific and sustainable soil and water conservation measures. They will be able to draw relevant conclusions from limited sources of data and information, to present it in a convincing manner and defend it in front of other stakeholders and use different tools and schools of thoughts to assess problems and find adapted solutions.

1.3 Land degradation problems and causes

According to Blaikie and Brookfield (1987) and Blaikie (1989) land degradation is the reduction in the capacity of the land to produce benefits from a particular land use under a specified form of land management. On the other hand, according to Douglas (1994) and Hurni (1993) the unhindered degradation of soil can completely ruin its productive capacity for human purposes and may be further reduced until steps are taken to stop further degradation and restore productivity. This definition embraces not only the biophysical factors of land use but also socioeconomic aspects such as how the land is managed and the expected yield from a plot of land (Steiner, 1996). Agricultural use degrades soil in the long run and reduces its fertility if it is not accompanied by soil conservation measures. Only suitable cropping methods and more or less labor-intensive or capital-intensive measures can sustain soil fertility (McNeill and Winiwartez, 2004).

The speed and extent of soil degradation depend on different factors, such as soils, relief, climate and farming systems (intensity of use). Soil loss can be 20 to 40 times higher than the rate of soil formation, which means there is no hope of restoring destroyed soils within a time span that bears any relations to human history (Steiner, 1996). Information on the economic impact of land degradation by different processes on a global scale is not available (Eswaran et al., 1999b). Some information for local and regional scales is available and reviewed by Lal (1998a). In Canada for example, on farm effects of land degradation were estimated to range between US$ 700 to US$ 915 million in 1984 (Girt, 1986). The economic impact of land degradation is extremely severe in densely populated South Asia, and Sub-Saharan Africa (Reich et. al., 2001; Eswaran et al., 1999a, Eswaran et al., 1997; Hurni, 1993). On plot and at field scales, erosion can cause yield reductions of 30 to 90% in some restrictive shallow soils of West Africa (Lal, 1998b; Mbagwu et. al, 1984). Yield reductions of 20 to 40% have been measured for row crops in Ohio (Fahnestock et al. 1995) and elsewhere in Midwest USA. In the Andean region of Colombia severe land degradation problems are observed (Ruppemtahal, 1995). Few attempts have been made to assess the global economic impact of erosion. The productivity of some lands in Africa (Hurni, 1993; Dregne, 1990) has declined by 50% as a result of erosion and desertification. Yield reductions in Africa (Lal, 1995) due to past soil erosion may range from 2 to 40%, with an annual mean loss of 8.2% for the continent. If accelerated erosion continues unabated, yield reductions by 2020 may be 16.5%. Annual reductions in total production for 1989 due to accelerated erosion was 8.2 million tons for cereals, 9.2 million tons for roots and tuber crops, and 0.6 million for pulses. On a global scale the annual soil loss of 75 billion tons of soil costs the world about USD 400 billion per year or approximately USD 70 per person per year (Lal et al., 1998b).

Nutrient depletion as a form of land degradation has a severe economic impact at the global scale especially in sub-Saharan Africa. Stoorvogel and Smaling (1990) and Smaling (1998) have estimated nutrient balances for several countries in sub-Sahara Africa. Annual depletion rates of soil fertility were estimated at 22 kg N, 3 kg P, and 15 kg K per ha. In Zimbabwe, soil erosion results in an annual loss of N and P alone totaling USD 1.5 billion. In South Asia, the annual economic loss is estimated at USD 600 million for nutrient loss by erosion, and USD 12'200 million due to soil fertility loss and depletion (Stocking, 1998). Globally there are an estimated 950 million ha of salt-affected soils in arid and semi-arid areas. Productivity of irrigated lands is severely threatened by build up of salt at the root zone. In Asia, annual economic loss is estimated at USD 500 million from water logging, and USD 1500 million due to salinization (UNEP, 1997). The potential and actual economic impact at the global scale is neither known for these degradation processes (Pimentel et al., 1995), nor for soil acidification and the resultant toxicity of high concentration of Al and Mn in the root zone, which is a serious problem in sub-humid and humid regions (Eswaran et al., 1997a).

Soil compaction is a worldwide problem, especially with the adoption of mechanized agriculture. It has caused yield reductions of 25 to 50% in some regions of Europe (Eriksson et al., 1974) and in North America, and between 40 and 90% in West African countries (Kayombo and Lal, 1994; Charreau, 1972). It is in the context of these global economic and environmental impacts of land degradation, and numerous functions of value to humans, which land degradation and desertification, are relevant. They are also relevant in developing technologies for reversing land degradation trends and mitigating the greenhouse effect through land and ecosystem restoration. As land resources are essentially non-renewable, it is necessary to adopt a positive approach to sustainable management of these finite resources. Land degradation mainly caused by soil erosion has been one of the chronic problems in Ethiopia (Berry, 2003; Nyssen et al., 2003a; Dregne, 1990; Hurni, 1988a). The decline of early civilizations, events of migrations, recurrent drought, famine and the dependency on food aid have contributed to this problem (McCann, 1995; Hurni, 1993; Mesfin, 1991; Pankhurst, 1986). The average annual soil loss from arable land in the highlands of Ethiopia was estimated to be about 42 tons per ha per year and the average annual productivity decline in cropland was 0.21% (Hurni, 1993). Further more the value of the total agricultural production loss due to soil erosion in the 1990s was estimated to be 32.2 million Ethiopian Birr, which according to Sutcliffe (1993) constitute 1.1% of the 1990 agricultural GDP.

All physical and economic evidence show that loss of land resource productivity is an important problem in Ethiopia and that with continued population growth the problem is likely to be more important in the future (Hurni, 1993). There are several studies that deal with land degradation at the national level in Ethiopia. These include the Highlands Reclamation Study (EHRS, FAO, 1986), the National Conservation Strategy (Sutcliffe, 1993), the Ethiopian Forestry Action Plan (EFAP, 1995) and studies on the effect of soil degradation on agricultural productivity (Keyser and Sonneveld, 2001) and on the environment (Nyssen et al., 2004a). Conclusions from these studies vary in detail. The EHRS concluded that water erosion (sheet and rill erosion) was the most important process and that in the mid 1980's 27 million ha or almost 50% of the highland area was significantly eroded, 14 million ha seriously eroded and over 2 million ha beyond reclamation. Erosion rates were estimated at 130 tons per ha and year for cropland, and 35 tons per ha and year on average for the entire highlands. But even at that time estimates were regarded as high. In the highlands of Ethiopia, the area of greatest livestock density and the area of major land degradation, recorded measurements of soil loss by water erosion range from 3.4 to 84.5 tons per ha per year with a mean of 42 tons per ha per year (Nyssen et. al., 2003; Shibru, 2003; Hurni, 1993; Hurni, 1987b). This represents a loss of 4mm of soil a year, which is twenty or more times replacement rates (Hurni, 1993). Keeping in mind that losses are unevenly distributed, many locations are even more seriously affected. Local benefits of re-deposition of eroded material may be rare, since many re-depositions are far away. In addition, the effect of physical soil loss is accompanied by nutrient loss, especially nitrogen and phosphorus, and estimates of these losses from, are considerable (Bojö and Cassells, 1995; Sutcliffe, 1993). As estimates of the severity of land degradation in Ethiopia vary so do cost estimates (Bojö, 1996).

The Ethiopian Forestry Action Plan stipulates the pattern of deforestation. The current rate of deforestation is estimated at 150'000 ha per year or 62'000ha per year (World Bank, 2001). Forests in general have shrunk from the original cover of 65% of the country, and 90% of the highlands, to currently 2.2% and 5.6%, respectively. Keyser and Sonneveld (2001) attempted a detailed national assessment of soil degradation on the basis of the UNEP grid DATA. This study indicates that soil degradation has its impact on soils of lower fertility and where population density is low; on fertile soils, land degradation tends to be compensated by fertilizer applications and many areas populated by a large percentage of people are in a critical state, where fertility loss needs to be compensated urgently by external inputs, and/or soil conservation measures need to be implemented, particularly in the most vulnerable areas in Northern Ethiopia.

In addition to these general statements, current reports (Berry, 2003; EARO, 2002; Pender et al., 2002; UNDP, 2002) on specific issues show:

- a loss of 30’000 ha annually due to water erosion, with over 2 million ha already severely damaged;
- a total loss of 4’000 ha of state farms due to severe salinization;
- nutrient depletion of 30 kg per ha of nitrogen and 15-20 kg per ha of phosphorus;
- a loss of 62’000 ha of forest and woodland annually.

Generally, in Ethiopia the crop yield per year is expected to decline by one to three percent, while the population is growing at the rate of 3.3%. Therefore, this scenario implies the challenge of feeding the present and future population on one hand while ensuring sustainable land management on the other.

The main causes for land degradation are complex and attributed to a combination of biophysical, social, economic and political factors. There are different views on the causes of land degradation: many indicate that population pressure to be the main cause for deforestation, overgrazing and expansion of cultivation into marginal lands. High population density is not necessarily related to land degradation; it is what a population does to the land that determines the extent of degradation. People can be a major asset in reversing a trend towards degradation. However, they need to be healthy and politically and economically motivated to care for the land, as subsistence agriculture, poverty, and illiteracy can be important causes of land and environmental degradation. On the other hand there are emerging evidences that areas with high population pressure are centres of innovations and land care practices (Tiffen et al., 1994). Growing populations clearly mean more pressure on natural, human, economic and other resources including soils. On the other hand, various studies indicate that food requirements can be met using current available technology and without making excessive damage to the environment even if the world population doubled. However, these studies do not necessarily include estimations on possible implications for global soil degradation and other environmental impacts (Gisladottir and Stocking, 2005; Lal, 2005). Soil degradation has been a major cause for food shortages in many places. Higher population pressure on land may thus have negative effects if no proper corrective measures are taken. Yet, higher pressure on land because of over-exploitation may also be induced by intensification of agriculture in countries, regions, localities and farms with little population growth. Depending on many other social, political, economic and environmental conditions, population growth, development of innovation and the rational use of technology all go hand–in–hand and can lead to both positive and negative impacts.

World wide, a large array of soil conservation measures and approaches are in use (Liniger et al., 2004). Although the immediate causes and impacts of soil degradation are generally well understood, it is far too simplistic to say that this understanding leads to the reversal of soil degradation. There are many reasons why soil degradation still occurs. An appraisal of different soil conservation technologies must therefore take into account not only the technological means involved but also the approaches that are supposed to grant successful implementation of measures, the socio-economic environment, markets, infrastructure, extension and other services, and the socio-cultural structures. Conservation issues are thus neither merely a technical matter, nor can they be resolved through legislation. It is necessary to address also socio-economic aspects of land use and to link incentives to sound land use practices (Fitsum and Holden, 2003; Hurni and Meyers, 2002). Similarly many have concluded that land degradation is a widespread problem with a widespread failure of interventions. As the cause of soil degradation is perceived at different levels ranging from single plots to global economy, so can solutions. In some cases it may be appropriate to seek solutions solely at household or community levels. In other cases, however, solutions identified at the local level need to be matched with national and global policies and actions (Hurni, 1998).

Despite intensive soil and water conservation activities since more than two decades ago, adoption of the interventions in Ethiopia is considerably rather low. This fact is frequently attributed, among other things, to the top-down approach in extension activities, standard – mainly structural – soil and water conservation technologies, lack of awareness of land degradation by the land users, and land security issues. Several approaches to extension delivery systems were exercised in Ethiopia. In most of the cases they were focused on either crop production or livestock husbandry. Extension on natural resources management was neglected at most, and if addressed, it was marginalized (EARO, 1998).

Generally the extension system on land and natural resources management in Ethiopia has the following major features (Arega and Hassan, 2003 Tesfaye, 2003; Yohannes, 1998):

It is based on the assumptions that

- population pressure is the fundamental cause for land degradation;
- poverty prevents small farmers from using adequate resources conservation techniques;
- farmers will only invest in soil and water conservation activities if land security is guaranteed;
- structural soil and water conservation measures are less attractive to small farmers because they have only long-term benefits;
- farmers do not adopt introduced soil and water conservation technologies because of their ignorance;
- ineffective indigenous and traditional practices result in further land degradation, famine and drought; and that
- poor farmers in general are less interested in conservation due to its long-term impact.

1.4 Approaches in soil and water conservation extension

The major Soil and Water Conservation extension approaches which were based on catchment treatment under watershed and integrated agricultural development include: Food for Work, Cash for Work, Local Level Participatory Approaches (LLPPA), Employment Generation Schemes (EGS) and the dominant regular approach is Participatory Demonstration, Extension and Training Systems (PADETS). These approaches are dominantly characterized by group approach, incentives (cash and food) and campaign works. If we consider different indicators such as participatory versus top down approach, facilitation versus controlling, sustainability versus short-term benefits, stimulation versus dependency, there are gaps that are to be addressed. In most cases what was perceived as participatory was in fact a top-down approach where the extension agent was forcing follower farmers to passively render their plots of land for experimentation rather than proactively engaging. Extension personnel were viewed as controllers and enforcers of government decrees rather than facilitators of transfer of technologies. In actual terms short-term benefits were emphasized rather than on long-term impacts since natural resources management is a long-term endeavor. Paradoxically the extension system imparted the “sense of dependency” syndrome on the part of farmers rather than stimulating them for better productivity (Fetien et al., 1996). Generally, in the whole state of the art farmers are considered an object of welfare rather than actors of development.

In the top-down approach, soil conservation technologies were selected on the basis of technical criteria rather than according to the financial costs and benefits associated with their adoption. Recommended land uses were determined according to the biophysical capability of the land, hence the focus was on the land's physical limitations (e.g. slope, soil texture, soil depth etc.) and erosion risks, rather than on the needs and social, cultural and economic circumstances of the land users. The overriding concern was to control runoff in order to prevent loss of soil by gullying. Understandably the past emphasis was laid on structural SWC to stop runoff either by trapping it in situ (tied ridging, backward-sloping contour terraces and Fanya juu), or by discharging it in protected waterways (storm drains, diversion ditches, graded bunds and artificial waterways). There has been far less awareness of the potential for improved agronomic and vegetative/biological measures to reduce soil loss and more importantly to maintain and enhance overall productivity.

The past approach emphasized planning at the watershed/ catchment level rather than individual farm level. Hence the boundaries of hydrological units (catchments) have typically been used to demarcate planning areas rather than the boundaries of administrative units (villages, peasant associations, districts). When farmers proved unwilling to voluntarily adopt the recommended soil conservation technologies, the common practice was either to force them to do so by means of coercive legislation, or "bribe" them to do so by means of donor-driven direct incentives (cash payments, food for work and free inputs). The end result has often been inflexible projects and programs, with a heavy emphasis on engineering and reforestation solutions. Farmers have typically been offered one conservation package (e.g. terracing) rather than a choice of alternative practices (menu of options) from which to choose those that match their particular needs and circumstances.

With such top-down planning, the target beneficiaries are largely passive recipients of externally conceived development proposals, all too often resulting in a lack of enthusiasm for project implementation by the intended beneficiaries, with poor establishment and maintenance of whatever physical structures, hedgerows, and woodlots were promoted. Participation, where it has occurred, has typically been a case of the professionals gathering data, analyzing it, preparing plans and then asking the local community if they agree, before requesting mobilization of local resources (notably labor) to implement these plans. Farmers have to date, limited opportunity to be actively involved in development and decision-making processes inherent in the management of their own areas and even less in policy formulation.

1.4.1 Approaches in the development of soil and water conservation technologies

The soil and water conservation technologies introduced by both government extension system and NGOs working at grassroots level is predominantly biased to standard structural SWC technologies. Again these technologies are biased towards reducing soil loss rather than to enhancing and increasing agricultural production. Awareness creation among the land users is considered as complementary activity by the extension systems. Less attention is given to indigenous practices and farmer's competence to solve their problems, which is usually underestimated and given less emphasis in the design of land management practices in the different extension approaches. Extension agents were not in a position to include indigenous knowledge into the package of practices they were extending (Eyasu and Fantaye, 2001; Mitiku et al., 2001; Tenna et al., 2001; Tilahun et al., 2001; Yohannes and Herweg, 2000).

1.4.2 Approaches to evaluation methodologies in soil and water conservation

Under the current monitoring systems of many institutions dealing with soil and water conservation at community level there seems some confusion with the concepts of some terminologies, which might lead to wrong conclusions and implementations. **Households** are endowed with different **plot** types that are managed in accordance to the typical plot characteristics. Some are in valley bottoms that may need drainage, some could be on sloppy lands that require conservation measures to harvest moisture and retain soils, and others could be near an irrigation canal with opportunities for intensive cultivation. However the systems have not considered the household livelihoods in designing the technologies. Such oversights usually fail in looking into the socio-economic conditions of the communities but dwell only on the attributes of the changes that can be monitored on the structures that are built. The farmer will manage the resources at his disposal depending on his labor and income. A farmer will weigh his **failures** and **successes** in a holistic manner rather than through attributes such as conserved or not conserved. Moreover, once a technology is adopted, the farmer through time and accumulated experience will adapt the introduced technology to fit into his resource endowments.

1.4.3 Approaches in soil and water conservation training and research

Courses related to land resources (forests, soils, water, etc.) are offered at institutions of higher education in Ethiopia. Land resources management is provided consolidated into soil science disciplines where the emphasis is more in managing the soils for crop production. In some institutions such courses are not even considered as requirement for earth science students. This approach is still prevalent at faculties of agriculture offering under-graduate courses. Soil and water conservation is usually provided from the viewpoint of agricultural engineering. Such approaches lack a more holistic perspective, e.g. sustainability of land management is not addressed at all or is left for other disciplines (plant science, agronomy, land husbandry, etc.). The Asmara University offered soil and water conservation as a discipline in the late 1980s as a degree program. Eventually, when the College of Dryland Agriculture and Natural Resources was established in Mekelle, the Department of Soil and Water Conservation was maintained for offering the training. After the establishment of Mekelle University, the college was transformed into the Faculty of Dry Land Agriculture and Natural Resources and the former department was changed into the Department of Land Resources Management and Environmental Protection (LaRMEP) to cater the emerging needs of addressing the biophysical, economic, socio-cultural and environmental aspects of sustainable land management.

With the advent of issues of sustainability in land management particularly after the Brundtland report (1987) faculties offering land related courses started to be challenged to include aspects of sustainable land management. Although attempts were made to revise some course materials to include aspects of sustainability into existing courses, the changes were not sufficient enough to incorporate and introduce stand-alone courses or supplementary courses in the different faculties. This mainly stems from the lack of research information on land resource management in the country (Paulos et al., 2002; EARO, 1998). Since the research undertaking in the country was for the main focused on crop science, research funding for land resources studies was at the bottom of the priorities (EARO, 2002). Hence any training to be offered by the different faculties pertaining to sustainable land management was not based on the Ethiopian bio-physical and economic context, but frequently used examples from Kenya, USA, etc., depriving access to the students with actual scenarios of the Ethiopian situation in land management, thereby incapacitating the trainees to make decisions on the actual situation of the country.

Research initiatives in soil and water conservation were made at the Alemaya University of Agriculture in the early 80s with a major emphasis on in-situ water conservation for crop production. Attempt was not made to investigate the major causes of land degradation and the extent of soil erosion damage in the region. The approach was more focused on agronomic solutions to reduce soil loss. Graduate research supervised by the faculty was more linked to the field and laboratory studies with very limited involvement of the local communities to which the research results are targeted.

The Institute of Agricultural Research (currently Ethiopian Agricultural Research Organization, EARO) concentrated mainly on soil fertility studies for crop production, without even understanding and inventorying the soil resources of the stations on which improved soil based technologies were tested. As a result, most of the fertilizer recommendations are basically blanket applications rather than crop and soil specific. In the mean time the problem of land degradation was going unabated particularly in the highlands of the country (Sutcliffe, 1993) and the research establishment was not either concerned with the magnitude of the problem of land degradation and its impelling perils on the productivity of the land or was biased to the only system of commodity improvement stipulated in the objectives of the institute (EARO, 2002). It was after the reorganization of the institute that token references and budgetary provisions were afforded for research on land resources.

In an attempt to address soil erosion problems, the Ethiopia Highland Reclamation Program was constituted under the Ministry of Agriculture in the 1980s. Important documents were produced focused more on physical structures than on matters related to sustainable land management. The Water Resources Ministry conducted studies and analyses on the rate of siltation on major river basins (Awash, Tekeze, Wabe, Shebele, Abay etc.) in the process of identifying potential dam sites. ILCA (now ILRI) was involved in soil and water conservation activities and studies in their attempt of pond construction using oxen power. Different forage sources were also screened for their role in stabilizing bunds and in the improvement of drainage systems mainly in Vertisol areas. NGOs were involved in the early 1970s on soil and water conservation activities particularly to mitigate drought and famine. These activities were in a form of technology transfer from other countries. Since the transfer was not commensurate with the socio-economic condition of the communities the impact was either lost or not documented at all.

From its inception in 1981 the main objective of the Soil Conservation Research Program (SCRP) was to support soil conservation efforts in Ethiopia by monitoring soil erosion and relevant factors of influence, by developing appropriate soil and water conservation measures and building local and international capacity in the field of research. From the beginning, the SCRP was attempting to develop appropriate technologies, which are technically feasible, ecologically sound, economically viable and socially acceptable. The environment of operation of the SCRP as a research supporting an on-going effort to mitigate land degradation was to provide appropriate technologies and test them in large operational scales. The centralized planning, massive campaigns, lack of incentives to farmers, weak technical and implementing capacity of the development agents and the land holding insecurity were not conducive for the scaling-up of the soil and water conservation activities as expected. No doubt a lot of guidelines and reports have been published and produced to help and support researchers and implementers design appropriate technologies. This can be verified through the mushrooming of soil and water conservation activities all over the country although at different pace. In the northern, central and eastern highlands of the country several farms and sloppy lands are elaborately terraced and conserved.

Vegetative conservation measures are being incorporated and several hectares of degraded lands are being excluded from anthropogenic activity to rehabilitate the land. Enabling environments that were not in place when the SCRP was operating are now available. These enabling environments in the form of decentralization, participatory planning, training of development agents and farmer schools have created a conducive situation for the implementation of the research recommendations drawn out by SCRP.

However, the research on its own could not elaborate truly innovative solutions for the complex and diverse cause and effect of land degradation problems. The information generated by the SCRP since 1981 is the most extensive and comprehensive database in Sub-Saharan Africa. It is hoped that many more researchers and experts will make use of it. That is also why this textbook is based on the exploitation of such valuable source of information for training future researchers, policy makers and trainers in sustainable land management.

2 Soil Degradation with a Focus on Soil Erosion

2.1 Soil functions

Besides water and biodiversity, soil can be considered one of the renewable natural or land resources. The term "renewable" is used if the time of regeneration would not take longer than approximately the lifespan of human beings. The term "resource" indicates that the soil is being perceived through its functions for the benefits of society (Figure 2.1):

- **Production functions:** capacity of the soil to produce food, fodder, fuel, fiber and construction wood; raw material and mineral resources to manufacture pottery, bricks, etc.
- **Physiological functions:** value of the soil for producing nutritive plants, decomposition of pollutants, filtering water, etc.
- **Cultural functions:** soil as the dwelling place of ancestors, family and social security, "stemming from the soil", etc.
- **Ecological functions:** soil as a value that controls energy, matter and water flows; storage of water, nutrients and pollutants, etc.

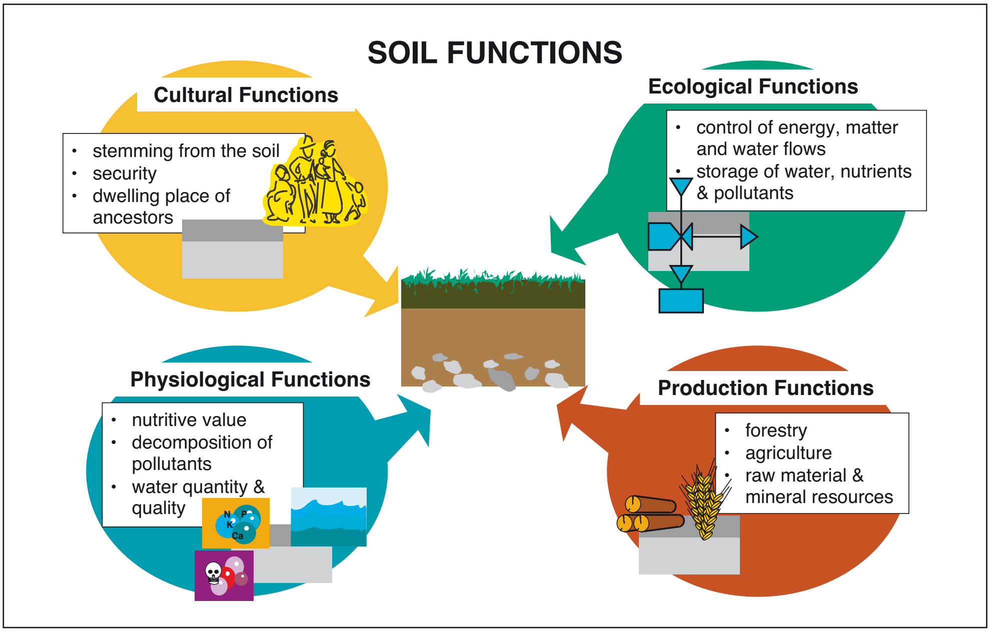


Figure 2.1: Soil functions (Drawing: Karl Herweg)

2.2 Global aspects of soil degradation

There is a lot of debate about whether long-term changes in climate have affected the soils in the past. As quoted by Hudson (1995), Reifenberg (1955) argued that there was no climatic change that has drastically resulted in land degradation. By contrast, Parry (1978) suggests that climatic changes may have been more important than previously assumed. However, the evidence from protected monastery and church forests suggest, whether or not climate has been a contributing factor, the land degradation observed today is human-induced phenomenon. Deforestation, agricultural over-utilization and overgrazing are according to GLASOD (1990) the major anthropogenic factors in soil degradation. A similar study in Ethiopia has also confirmed that human induced mismanagement of natural resources is a root cause of soil degradation together with the concomitant climatic changes (Dramis et al., 2003; Nyssen et al. 2003a).

“Utilizing” natural resources such as soils basically implies the risk of overusing and degrading these resources. The term **soil degradation** comprises a whole palette of human induced degrading processes, out of which **soil erosion** by water is considered the most prominent one. The “Global Assessment of Human induced Soil Degradation” (GLASOD, 1990) under the United Nations Environment Program (UNEP) states that about one-sixth of the earth’s terrestrial surface, including one-third of its agricultural land, is already affected by human-induced soil degradation (cf. Figures 2.2, 2.3, and Table 2.1). GLASOD distinguishes four human induced processes of degradation: water erosion, wind erosion chemical and physical degradation. According to Oldeman et al. (1990, 1991) and Oldeman (1994), worldwide 56% – in Africa 46% – of all human-induced soil degradation results from soil erosion by water, and 28% from wind erosion. The most important forms of chemical soil degradation are loss of nutrients and organic matter (South America, Africa) and salinzation (Asia). The main reasons for chemical soil degradation are agricultural mismanagement (56%), and deforestation (28%). The most important causes of erosion by water are deforestation (43%), overgrazing (29%) and agricultural mismanagement (28%). The main causes of wind erosion on the other hand are, overgrazing (60%), agricultural mismanagement (16%), overexploitation of natural vegetation (16%) and deforestation (8%).

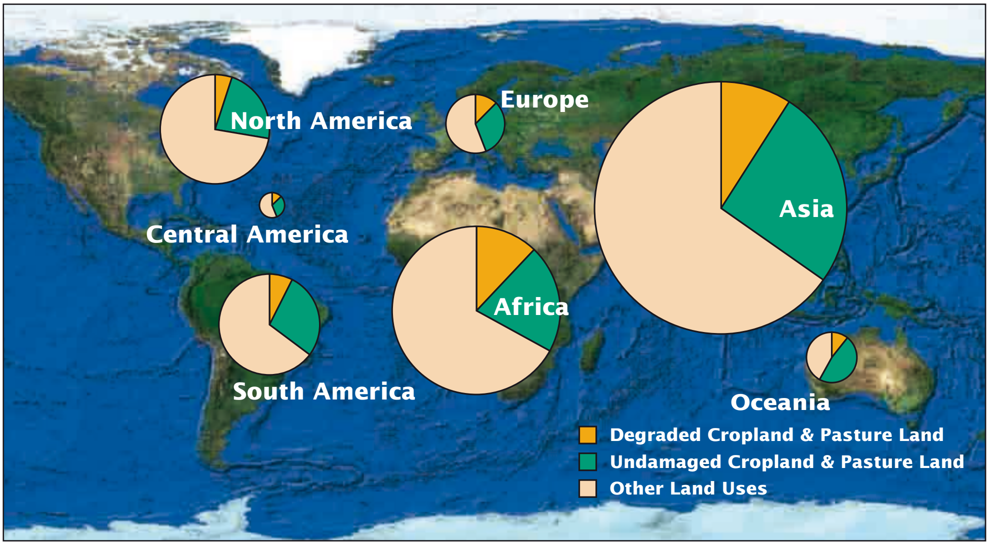


Figure 2.2: Global degradation of crop and pasture lands (Source: GLASOD, 1990)

Table 2.1: Soil degradation processes and causes contributing to continental and global soil degradation (%)

	World	Europe	N & C America	South America	Austral-asia	Asia	Africa
Processes							
Erosion by water	55.6	52.3	67.0	50.6	81.0	58.0	46.0
Erosion by wind	27.9	19.3	25.0	17.2	16.0	30.0	38.0
Chemical deterioration	12.2	11.8	4.0	28.8	1.0	10.0	12.0
Physical deterioration	4.2	16.6	4.0	3.4	2.0	2.0	4.0
Causes							
Deforestation	29.5	38.3	11.3	41.3	12.0	41.0	14.0
Overgrazing	34.5	22.8	24.0	27.8	80.0	26.0	49.0
Over-exploitation	6.7	0.2	7.2	4.8	-	6.0	13.0
Agric. activities	28.1	29.3	57.2	26.1	8.0	27.0	24.0
(Bio-) Industrial	1.2	9.4	0.3	-	-	-	-

Source: GLASOD, 1990

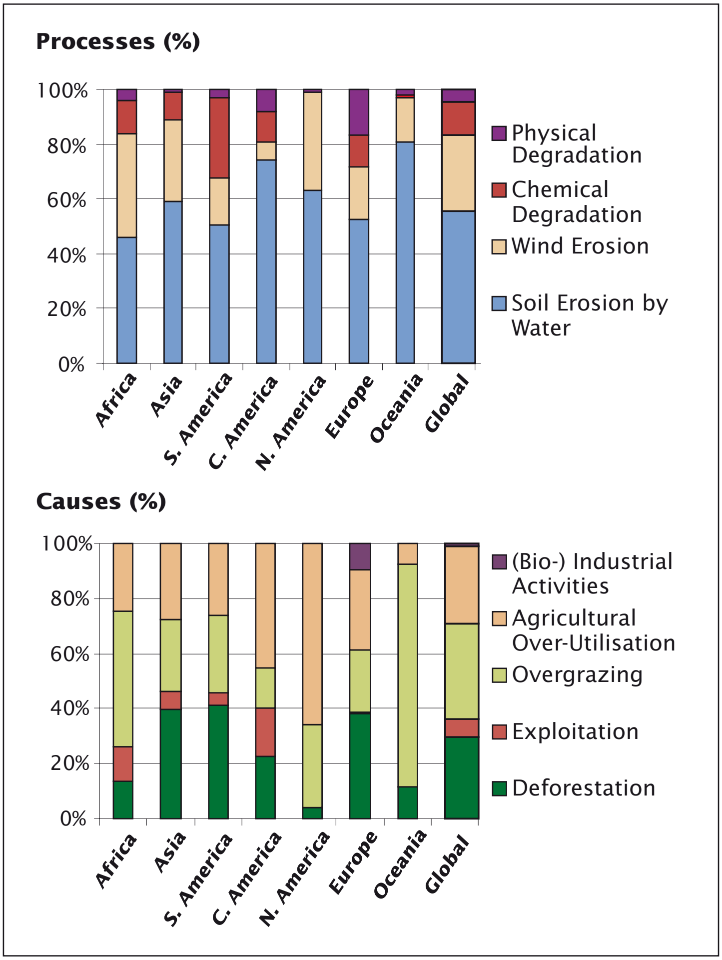


Figure 2.3: Major processes and causes of human induced soil degradation (Source: GLASOD, 1990)

Processes vary with climate and land management systems. Leaching, acidification and soil erosion by water are prominent processes in humid and sub-humid areas, besides nutrient depletion due to inadequate fertilizer application, and depletion of organic matter due to faster decomposition and insufficient application of organic fertilizer. Desertification, a process involving salinization (due to inadequate irrigation and drainage, 12% of all damage), erosion by wind and water, and compaction (4% of all damage), is typical of arid, semi-arid and drier sub-humid areas. Industrialized countries are facing high toxicity and compaction due to mechanized and industrialized agriculture with high fertilizer input, or due to waste as a result of urbanization, industries, infrastructure development and mining. The GLASOD maps show physical degradation particularly in the temperate zones, probably due mostly to compaction as a result of using agricultural heavy machinery.

These figures need to be handled with care since the GLASOD results are not based on field studies but on the opinion of soil and water conservation experts, but they give an estimation of the severity of soil erosion at the global scale. On-site, soil degradation leads to declining soil productivity, which primarily threatens the livelihood of rural land users (Figure 2.4). This affects about 2.6 billion people worldwide who depend directly on agriculture; the majority of them being subsistence peasants. Off-site impacts of soil degradation, such as flash floods, sedimentation of water reservoirs, water quality decline, mobile dunes or dust storms may affect society as a whole. Therefore, controlling soil degradation must involve all stakeholder groups of a society, not only rural land users (Hurni et al. 1996, cf. Chapter 9). "Solutions" must, therefore, not only be based on technologies but must also confront socioeconomic, cultural and political aspects, such as population pressure, loss of indigenous knowledge through HIV-AIDS, inequity in the global terms of trade, etc.

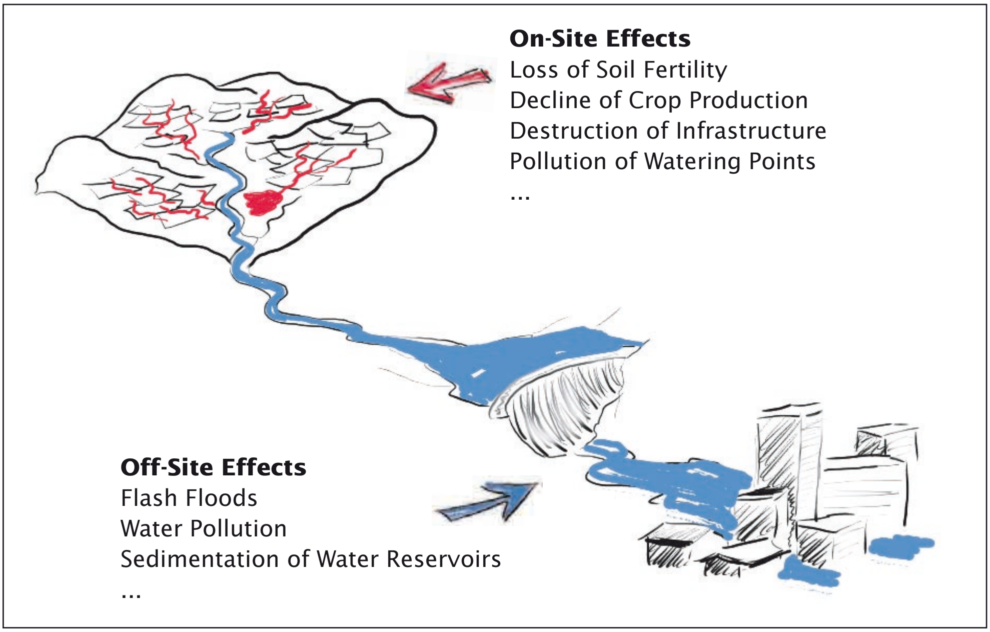


Figure 2.4: On-site and off-site effects of soil erosion (Drawing: Karl Herweg)

2.3 Types of soil degradation – a brief brush-up

Soil erosion by water and wind

According to the GLASOD study mentioned above, soil erosion is considered the most important soil degradation process, in particular soil erosion by water. Therefore, special emphasis will be given to soil erosion in the Chapters 2.4, 3, 4, and 5.

Physical (mechanical) soil degradation

Physical degradation basically includes a negative impact on physical soil properties, such as structure, texture, aggregate stability, porosity, permeability (compaction), and crusting. **Soil erosion** may be considered part of this category because it physically reduces soil depth. Furthermore, **soil compaction** is an increase in bulk density due to external load leading to the degradation of physical soil properties such as root penetration, hydraulic conductivity and aeration. Compaction usually occurs in mechanized farming systems, where the soil has to support regular heavy loads. In the tropics damage due to compaction is thus a particular problem with forest clearance machinery and in agro-industry. However, compaction can be triggered through grazing, even with low stock (Mitiku et al. 2004; Solomon, 1994). **Hard-setting** affects soils with extremely low structural stability that decomposes into primary particles when moistened and during drying harden to a very compact, impermeable mass without structure. Unlike soil compaction, no external load is necessary so hard-setting also occurs in traditional farming systems with predominantly manual labor (Breuer, 1994). Infiltration and water retention are very limited on hard-setting soils and plants cannot germinate or are seriously hampered. Tillage by hand or animal traction is often impossible and the land degenerates to badland. **Crusting** occurs due to several factors, e.g. the destruction of aggregates in the topsoil by rain, which is closely linked to soil erosion, an upward movement of water and soluble salts under semi-arid conditions, and the development of algae at the soil surface. Crusting reduces infiltration and promotes water runoff. It inhibits germination and emergence of seedlings. Lower infiltration rates reduce water retention capacity and aggravate drought stress.

Chemical soil degradation

A number of chemical processes impair soil fertility, and we can basically distinguish the depletion of plant nutrient reserves and **enrichment** of toxic substances (Dumanski et al., 1997a). According to Sanchez and Logan (1992) about 1.7 billion ha of tropical soils are low in nutrient reserves. These intensely weathered soils can supply only a limited amount of nutrients. Because of leaching, particularly in the humid areas, soluble nutrients from the root zone can be washed out and transported into deeper soil layers. **Acidification** produces aluminum and ferrous oxides leading to phosphorous fixation, which is rendered unavailable for uptake by plants. Phosphorous **fixation** is more frequent in the humid tropics, but it also occurs to a significant degree in savannas and steep highlands). In Andosols the fixation is a major problem because of allophane and volcanic soils in the humid tropics and tropical highlands are particularly affected.

In Sub Saharan Africa substantial quantities of nutrients are removed from agricultural soils during harvest (Balesh, 2005; Assefa et. al., 2004; Smaling 1998; Stangel et al., 1994). If the removed nutrients are not replenished through the application of fertilizers, manure, compost, biological nitrogen fixation or subsequent delivery through weathering soil minerals, the nutrient content of the soil will decline rapidly jeopardizing sustainable production. **Soil acidification** and **aluminum toxicity** are direct causes of leaching and nutrient export, decomposition of organic matter or root exudation. The use of acid reacting mineral fertilizers such as urea or ammonium sulfate can speed up the process. Studies by Sanchez and Logan (1992) show about one third of the tropical lands occur with highly acidic soils, which contain plant toxic Al in the soil solution. The level of aluminum saturation is higher than 60% in the exchange complex. The aluminum ions in solution directly damage the plant roots and thus reduce nutrient and water uptake. In Oxisols, Inceptisols and Ultisols the Al concentration in the subsoil increases significantly. This is attributed to the decline of soil fertility resulting from the denudation of top soils by erosion (Solomon, 1994). A quarter of tropical soils are acidic soils with pH values below 5.5 in the upper horizons but no effect of the aluminum on plant toxicity. Since these soils occur across all agro-ecological zones, they require higher fertilizer rates and liming than soils with higher pH values. In addition manganese toxicity may be encountered in acidic soils with a tendency of water logging.

In the tropics **salinization** poses a problem on 66 million ha. Out of these alkaline soils 78% contain a sodium saturation of more than 15% in the upper 50 cm of the soil. The problems affect less than 1% of the total land area but they constitute a major local impact, because the land concerned is often of high potential and capable of irrigation. Salinization can be classed as a specific form of chemical degradation. Salinization is often the result of a combination of improper irrigation, higher evapotranspiration, and human induced changes of hydrological regimes. Due to high osmotic potential of the saline soil solution, salinization reduces the amount of water available to plants. High concentration of some soluble salts will also cause toxic effects on plants and high **soil alkalinity** under the preponderance high level of sodium creates a dispersed system damaging soil structure impairing infiltration capacity.

Organic matter ensures favorable physical soil conditions, including water retention capacity. It furnishes balanced and slow-flowing sources of nutrients and is a basis for the cation exchange capacity (CEC). Particularly on soils with low-sorption clay minerals, organic matter plays an even greater role for CEC. In cropping systems involving repeated tillage, there is rapid **organic matter decline**, often within a few cropping cycles (Solomon, 1994). Nutrient retention declines below the necessary minimum and nutrient leaching increases by a large margin. Very low potential CEC is therefore gauged to be far more detrimental than a deficiency in particular nutrients, because, as estimates by Budelman and Van der Pol (1992) show, even if additional fertilizer is applied, cropping ceases to be economically viable when the potential CEC drops below 30-40 mmol/kg soil. Many processes affect the delivery and decomposition rate of organic matter, which is why the equilibrium collates with different levels of C content depending on the site. In the tropics organic matter decomposes about five times faster than in temperate climates (Sanchez and Logan 1992).

Biological soil degradation

Biological degradation is frequently equated with the depletion of vegetation cover and organic matter in the soil, but it also denotes the **reduction of biological activity**. It is a direct consequence of inappropriate soil management that also results in physical and chemical soil degradation. It is known that soil fauna is an indicator of soil fertility status and influences the structure of the soil. In the tropics termites play an important role in improving soil aeration and rising soil fertility (Swift and Sanchez, 1984; Lee and Wood, 1971). Earthworms play a role in temperate soils and they can perform a similar function to termites in some tropical soils, but they are not comparable in number and biomass (Young, 1976). The destruction of soil structure by compaction, water logging or crusting, impedes aeration and thus the supply of oxygen to the aerobic soil organisms; conversely this is conducive to the anaerobic organisms. Another component in this interaction is organic matter, which is itself beneficial to soil structure, while at the same time providing energy for most soil organisms.

Combinations of soil degradation processes

Degradation processes and phenomena as listed above rarely occur in isolated forms but rather in combination. They can be accelerated or slowed down depending on the prevailing land management practices. For example, upslope-downslope tillage may cause soil erosion by water, which in turn affects physical, chemical and biological soil properties and thus triggers a series of different degradation processes. On the one hand, nutrients can be removed by soil erosion from the surface, and they can be transported into layers out of the reach of plant roots by leaching. They can also be diminished due to intensive farming without compensation of nutrients, e.g. under monoculture without adding fertilizer, organic matter, compost, and other organic material. A reduction of organic matter, e.g. due to erosion or chemical degradation automatically leads to biological soil degradation. Decreasing plant cover and organic matter involves a decrease in soil biological activities (e.g. microbes, rodents, earth worms). A consequence of nutrient removal is acidification. On the other hand, an overuse of fertilizer, herbicides and pesticides, and improper management of irrigation schemes, in contrast, can contaminate the soils and lead to toxicity and salinity (Bruce, 2004).

2.4 Soil erosion by water – a specific form of soil degradation

Without human influence, **geological (natural) erosion** occurs at all times due to the interaction of climate (weathering, precipitation), vegetation (nutrient uptake, protective cover), parent material and topography. Nowadays, however, there is almost no part of the earth's surface that is not used by human beings (Eswaran, et al., 1997a). This human "factor" can speed up erosion, which is, therefore, referred to as **accelerated (human induced) soil erosion** (Figure 2.5). In view of a more sustainable land management it should be noted, though, that the "human factor" is also in a position to minimize soil erosion!

Soil erosion is defined as the detachment and transport of solid particles on the soil surface by water and wind. In the long term, this process leads to stable landforms with low erosion rates. From the production point of view, however, erosion leads mostly to a less favorable distribution of soil properties due to the selectivity of soil erosion. Eroded topsoil particles contain a higher percentage of clay minerals, organic matter and nutrients than the remaining (sub-) soil itself. This means that even a seemingly minor loss of topsoil per year can reduce soil productivity significantly in the long run. In addition, spatial soil fertility distribution easily changes to the worse: while fertility decreases by means of erosion on a relatively large area (e.g. ridges and slopes), the eroded fertile material deposits in deep accumulations covering only a relatively small area (e.g. valley bottoms). In natural ecosystems undisturbed by man, erosion is triggered by a coincidence of natural tectonic events that alter the relief, natural disasters that destroy the vegetation cover and climatic conditions that provide means of transport, such as water and wind. According to de Graaff (1993), determinants or direct factors of influence of erosion are rainfall (erosivity), vegetation (ground cover), topography (surface forms, slope inclination and exposure to sun), and soil properties (erodibility; Figure 2.6). Man changes three of these factors from their natural state – vegetation, topography and soil properties – and is therefore in the position to both accelerate and slow down the process of soil erosion.

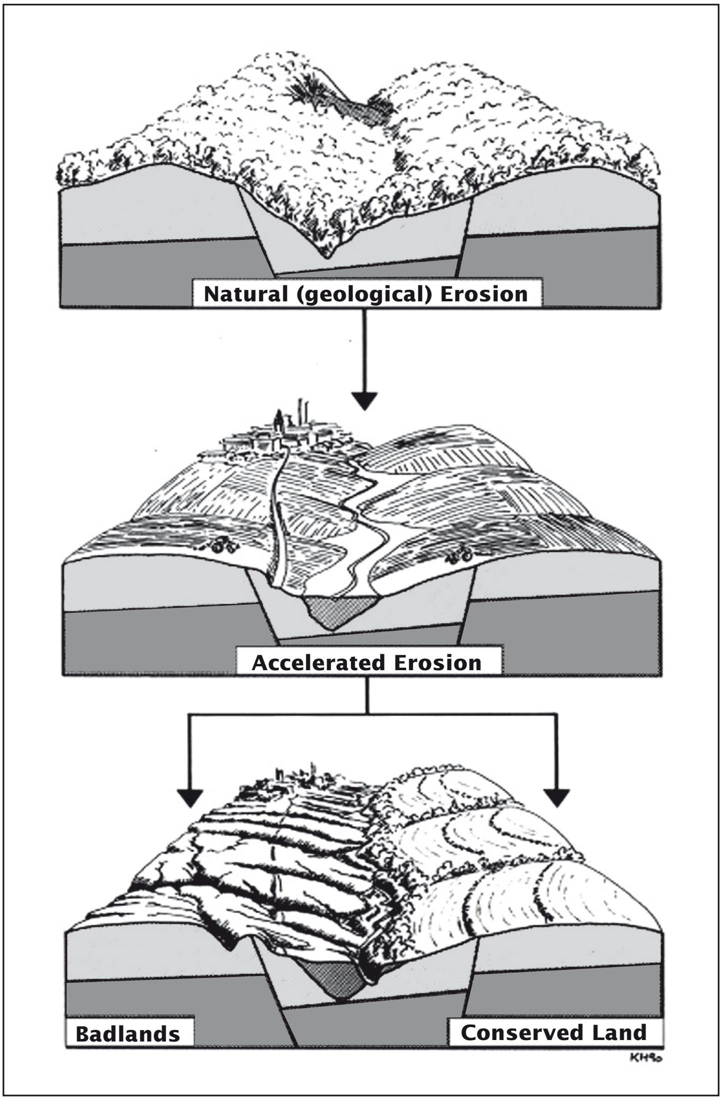


Figure 2.5: Natural erosion and accelerated soil erosion (Drawing: Karl Herweg)

2.4.1 Soil erosion processes and features

Detailed information on soil erosion processes is found in Bergsma (1996) and Bryan (1987). Water erosion is closely linked to the water balance (Figure 2.7). **Soil erosion features** are witnesses of a number of past erosion processes. The question is whether these processes took place recently (current erosion) or long time ago (past erosion).

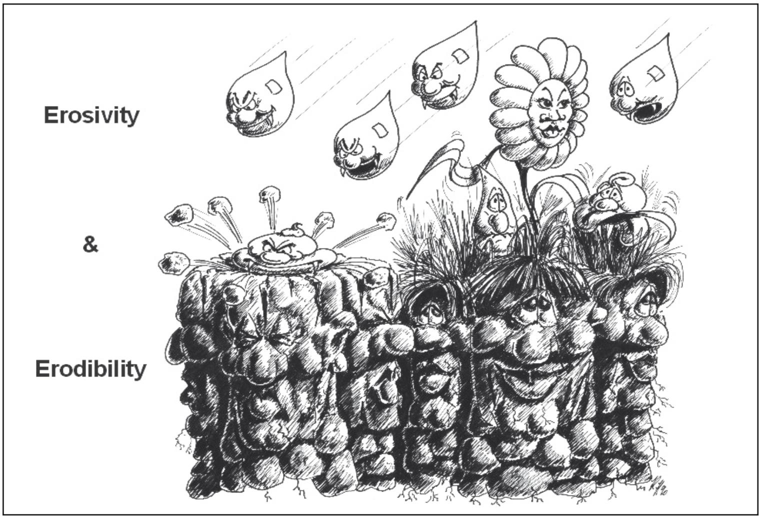


Figure 2.6: Erosivity and erodibility

Erosivity is a complex indicator that refers to the potential of rainfall to cause soil erosion. It contains parameters such as amount of rainfall, intensity, energy, etc. Erodibility refers to the vulnerability of the soil of being eroded. It may include parameters such as soil texture, permeability, soil organic matter, etc. Some authors also include vegetation cover as part of their erodibility concept. (Drawing: Karl Herweg)

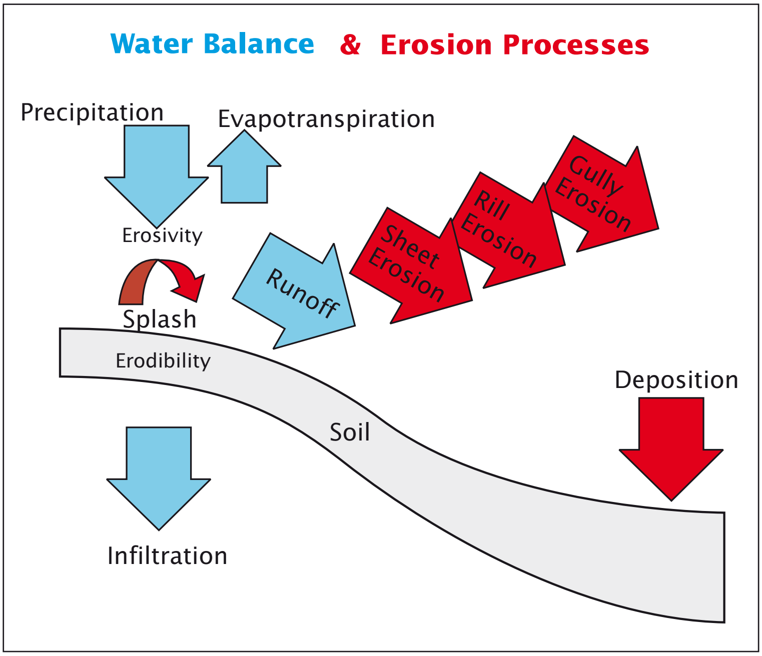


Figure 2.7: Water balance and processes of soil erosion (Drawing: Karl Herweg)

Main processes

- Rain-splash detaches soil particles through the impact of raindrops and can move them several meters through the air. These particles are prone to be washed away by sheet erosion.
- Water that cannot infiltrate in the soil is called **runoff (overland flow)**. As long as runoff does not concentrate, we talk about **areal** erosion, the so-called **sheet flow** (sheet wash, inter-rill) erosion, which moves particles prepared by rain-splash down slope. At the same time, runoff carrying soil particles loosens and picks up additional particles (entrainment). A freshly plowed or harrowed soil surface is usually characterized by a high surface roughness. After a number of rainstorms, splash, sheet erosion and diffuse accumulations smoothen soil clods and aggregates. **Low surface roughness (puddling effect)** is thus an indicator of recent erosion. This process is faster when aggregate stability is low.
- Particularly intensive rainstorms lead to concentrated runoff that produces more obvious features of **linear** erosion, which often occur on steep slopes and in depressions. If water concentration and flow velocity exceed the soil-specific threshold of adhesion, **pre-rill** erosion forms small and shallow rills with a depth of a few cm. Further development of pre-rills is called **rill erosion** if it forms channels up to 50 cm deep.
- **Gully erosion** may result from rill erosion. It forms channels deeper than 50 cm, which causes additional processes destabilizing the gully walls, such as small landslips. A riverbed, for example, can also be considered a permanent gully. Land that is dissected by gullies to an extent that any type of productive land use becomes impossible is called **badlands**.
- Precipitation in combination with infiltration may destabilize particularly steeper slopes and create mass movements such as **landslips** and **landslides** (Nyssen et al., 2002).
- Material that has been transported by rain-splash and sheet wash may be deposited in **diffuse accumulations** only a few meters away from its origin. This process is often visible as puddling effect, which contributes to sealing of the soil surface, reduced infiltration and increased overland flow.
- When runoff concentration and velocity diminish, the eroded material can be deposited in **concentrated accumulations** ("filter zones"). These are clearly visible in slope depressions with diminishing slope angle, on foot slopes and valley floors, along field borders, vegetation strips, and hedgerows, or above SWC structures.
- The temporary or permanent absence of vegetation, as in semi-arid areas, prepares the ground for another type of soil erosion: **wind erosion**. High-speed winds take up soil particles, particularly from a dry surface. During transport, those particles have additional impacts onto the surface and can thus mechanically loosen other particles. Wind erosion also creates a **smooth** and **sorted-out surface (desert pavement)** where the soil is eroded. Decreasing wind speed enhances **deposition**

(accumulation) typically both in front of and behind wind breaks, such as trees, live fences etc.

- Recent erosion features have rather **sharp** edges and are free **(devoid) of vegetation**. With time, the edges are rounded by rain splash and entrainment, and weeds and other vegetation start to cover the features. Other indicators of "old" or long-term erosion are **exposed plant roots**, or a **lowered soil surface**, e.g. visible along field borders. In case erosion has removed larger parts of the topsoil and subsoil material (truncated B horizon) is plowed up or weathered rocks become visible, the **color of the surface** becomes lighter and more variable.

It is important to keep in mind that data obtained with different measurement devices, such as test plots, sediment troughs, rill mapping, etc. always reflect a mixture of various erosion process.

Photo 2.1: Soil color as an indicator of erosion

Changes in soil color as it can be seen on this photo are often indicating the loss or reduction of the darker topsoil and the exposure of the lighter subsoil or parent material. In the centre of the photo, a relatively large area is affected by soil erosion. In the left part of the photo very light linear erosion features indicate a problem of uncontrolled drainage that originates from compacted footpaths and areas around the hamlets (Photo: Karl Herweg 1988).

Photo 2.2: Soil surface levels

Different land use can lead to an entirely different soil development, even if climate, parent material and the topography are similar. According to the Italian farmer who manages the land represented on the photo, there was always forest (macchia) on the left hand side, and on the right hand side cropland every second year alternating with pasture. He roughly estimated that this was the case for at least 150 years. The meter stick in the centre shows, that the soil surface of the crop- and pastureland, which was exposed to soil erosion and accumulation processes has lowered a couple of decimeters during this period of time. N.B. that such "steps" in the landscape may occur due to different reasons, and it needs to be confirmed, e.g. by soil profile analysis, if they can be attributed to soil erosion, as was done in this example (Photo: Karl Herweg 1986).

Photo 2.3: Gully erosion

Initially unspectacular rills can develop into gullies. The factors enhancing this are manifold. The example shows a landscape in Oromia, east of Addis Abeba. On the steep slopes in the *background surplus overland flow from all types of land use and field border erosion have created an intensively intersected slope. In the foreground, the vulnerable soil type – in this case a Planosol – has fostered gully erosion. Very often, also areas with compacted surface and low or zero infiltration contribute to the development of such erosion features. Land management operations are severely hampered (Photo: Karl Herweg 1988).*

Photo 2.4: Badlands
If gullies cannot be controlled they become deeper and wider. When most topsoil and considerable parts of the subsoil are removed vegetation growth is reduced to a minimum. Such severely eroded slopes of greater area coverage are called "badlands", as it can be seen in this example from Welayta (Photo: Karl Herweg 1988).

2.4.2 Direct factors of influence on soil erosion

Apart from land use activities that trigger soil erosion processes, there are a number of factors that directly influence or steer the process. These factors are strongly interlinked, which means they influence each other as well as the erosion processes. The examples given in brackets indicate how the factors influence soil erosion. Figures 2.8 – 2.12 illustrate or highlight some details. Table 2.2 indicates how these factors and parameters can influence soil erosion processes directly or indirectly.

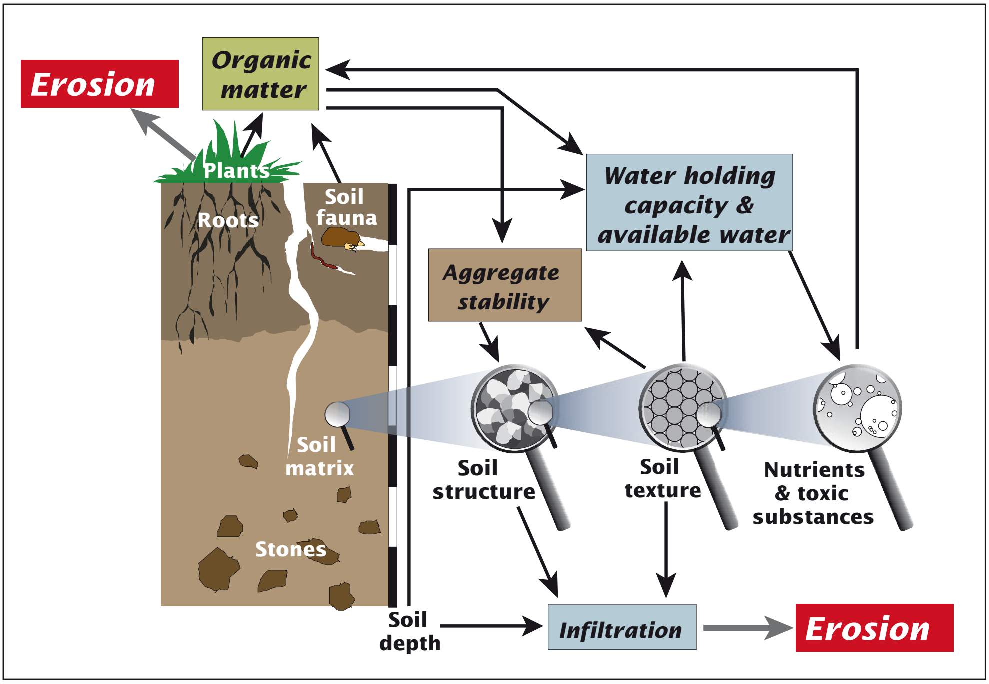


Figure 2.8: The influence of soil properties on soil erosion (Drawing: Karl Herweg)

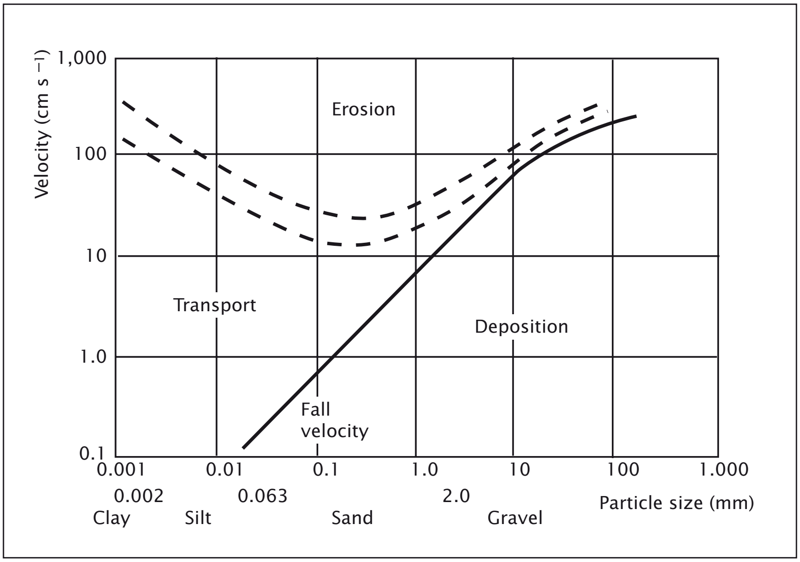


Figure 2.9: Critical water velocities for erosion, transport and deposition as a function of particle size (after Hjulström, 1935)

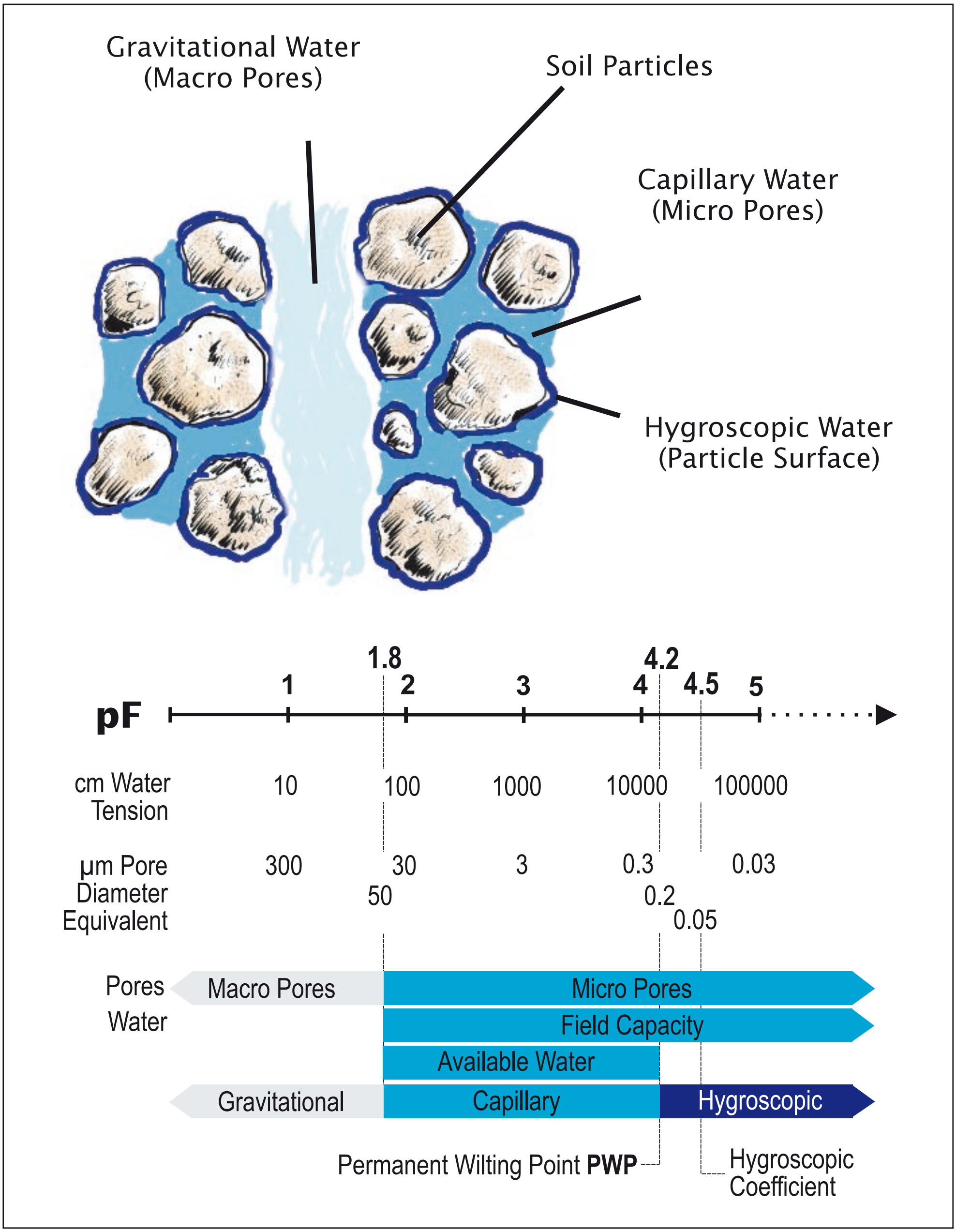


Figure 2.10: Brush-up: pore size, water tension and soil water (Drawing: Karl Herweg)

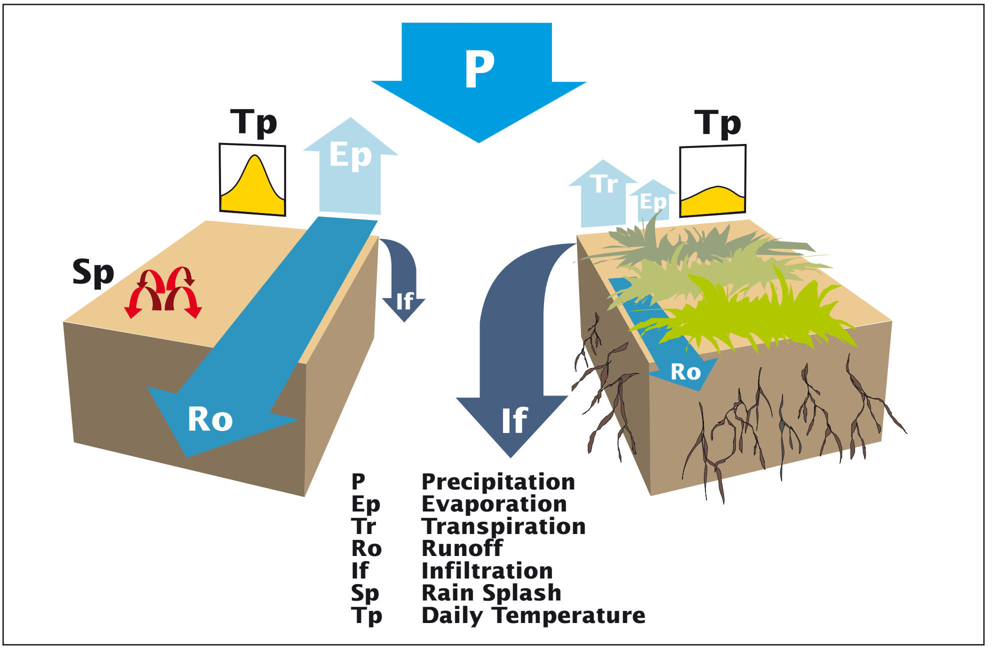


Figure 2.11: The influence of vegetation on soil erosion (Drawing: Karl Herweg)

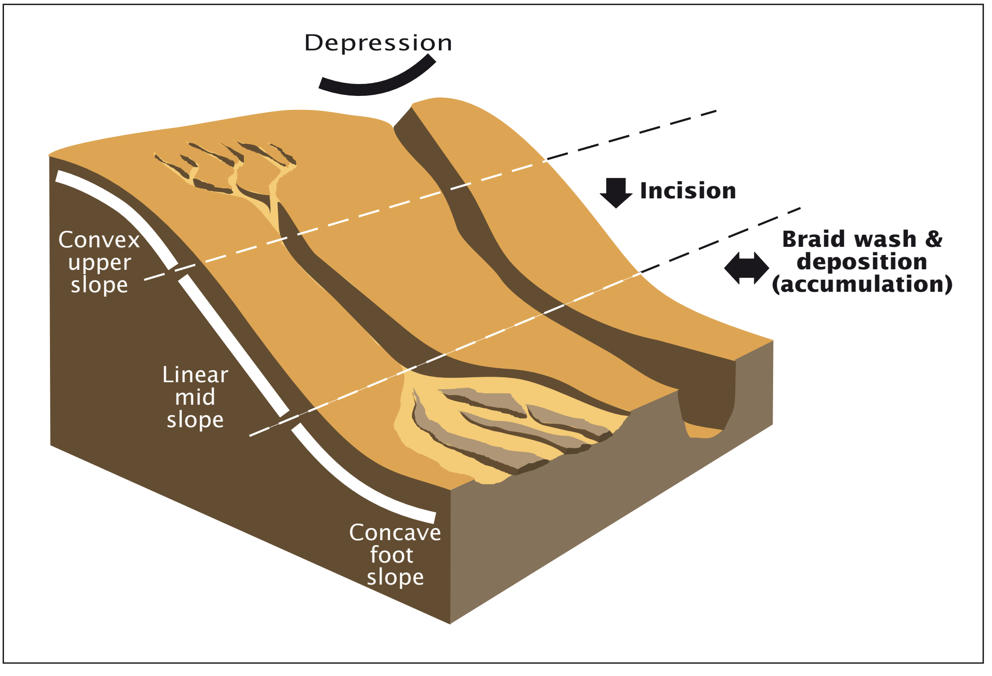


Figure 2.12: The influence of slope characteristics on soil erosion (Drawing: Karl Herweg)

Table 2.2: The direct and indirect influence (in brackets) of different factors on soil erosion processes

Climate
▪ Rainfall erosivity, amount, intensity, duration (detachment of soil particles)
▪ Wind speed (detachment of soil particles)
▪ Temperature (evaporation, soil moisture, infiltration / runoff)
Soil properties
▪ Erodibility, texture, soil organic matter, permeability (detachment of soil particles, runoff)
▪ Soil structure (infiltration speed)
▪ Soil depth (volume of infiltration)
▪ Surface roughness (runoff speed)
▪ Soil moisture, soil water (infiltration / runoff)
▪ Soil fertility and water holding capacity (protective plant growth)
▪ Surface stone cover (rain splash)
Topography
▪ Slope angle (runoff speed)
▪ Slope length (amount and speed of runoff)
▪ Slope shape (concentration and speed of runoff)
▪ Exposition (soil moisture, infiltration / runoff)
Vegetation
▪ Plant ground cover (splash, runoff velocity, accumulation)
▪ Plant height (drip and splash)
▪ Roots (infiltration)
▪ Organic matter (erodibility)
Soil management
▪ Crop rotation (fertility, ground cover)
▪ Tillage direction (runoff)
▪ Machines (compaction, infiltration)
▪ Timeliness of planting (cover)
▪ Fertilization (cover)

2.5 Questions and issues for debate

- Apart from the indicators of soil erosion mentioned in the text, do you know any "indigenous erosion indicators" (i.e. local indicators of farmers)?
- Vegetation, soil and slope parameters are, among others, major factors influencing soil erosion processes. You can brush up your previous knowledge by scrolling through the Figures 2.8 – 2.12 and Table 2.2, list **which** parameters can be changed by human activities, and describe **how** they could be influenced in order to minimize erosion.
- Which of the above mentioned factors of influence do you think have the most **dominant** impact on soil erosion rates, and why?

3 Soil Erosion Monitoring Methodology

3.1 Concept and methodology of the Soil Conservation Research Program of Ethiopia

The Soil Conservation Research Program (SCRP) was initiated in 1981 and after seventeen years of field research under the then Ministry of Agriculture, it was decentralized in 1998 when the research sites were brought under the responsibilities of regional authorities. The research concept of the SCRP involved the selection of benchmark sites with various socio-cultural settings in several different agro-climatic zones of the country (cf. Figure 3.1 and Annex 1). Data analysis and interpretation in the following chapters is based on more than 15 years of soil erosion and soil conserva-

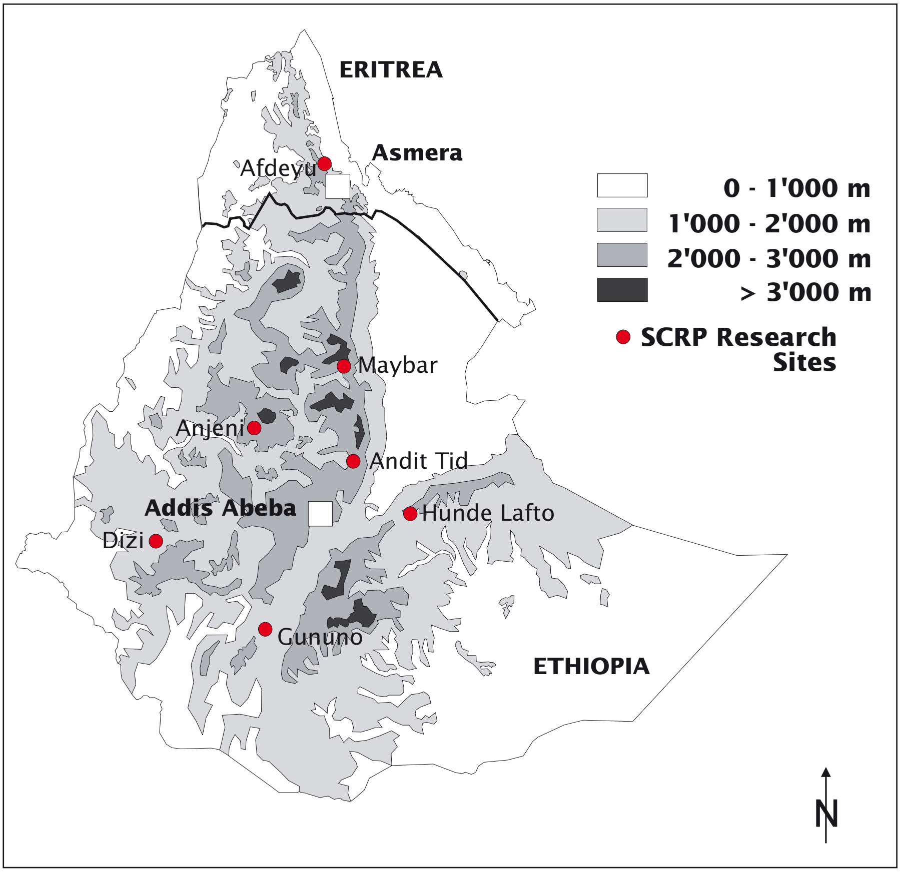


Figure 3.1: Research sites of the SCRP (Map: Brigitta Stillhardt)

tion research in the highlands of Ethiopia and Eritrea, where the SCRP maintained seven research stations in different agro-ecological belts. The general concept and methodology of the SCRP is described in Hurni (1982), Herweg and Hurni (1993), and SCRP (2000). Before embarking into the details of describing the research results and sites it is imperative to briefly dwell on the different zonation systems of Ethiopia as described by Hurni (1999).

3.1.1 Altitudinal zonation and agroecological belts

The agro-ecological zonation can be defined as a spatial classification of the landscape into area units with similar agricultural and ecological characteristics (Hurni 1999). Attributes of such units determine similarities, such as (1) comparable agro-climatic conditions for annual cropping, perennial cropping, or agroforestry; (2) similar conditions for livestock husbandry; (3) comparable land resource conditions such as soil, water or vegetation parameters; and (4) similar land management conditions such as ruggedness of agricultural land, slope steepness, or general topographic variations. Such attributes determining similarities of units can further be distinguished through on the spot verification of actual conditions and anticipated potentials. The former may be used to determine the actual agro-ecological differentiation of farming systems as they manifest today. Potential similarities, on the other hand, are more concerned with the assessment of general land capability, or suitability, for specific crops. Usually, an agro-ecological zonation is used to improve the planning of agricultural development, be it in the areas of forestry, cropping, or livestock management and improvement. Ecological conditions usually relate to climatic parameters such as rainfall amount and variability, temperature or frost hazard, vegetation characteristics (types, composition, natural or man-made), and further important parameters that permit ecological differentiation such as soil and water characteristics.

Particularly in mountainous countries altitude and topographic characteristics such as steepness and slope play an important role in agro-ecological zonation. In Ethiopia, where the most pronounced mountain system in Africa is found, altitudinal gradients and variability have been recognized as primordial parameters for agro-ecological zonation (Hurni 1998). When it comes to the vertical zonation of major agro-ecological characteristics in mountains the term “belt” is used to indicate these variations (Hurni, 1998). According to Alexander von Humboldt (1769-1859, quoted by Hurni, 1999) a distinct differentiation of vegetation was observed in the Andean mountains along the north-south extension. This historic methodology was re-used and applied in the development of the agro-ecological belts of Ethiopia (Hurni, 1999).

3.1.2 Traditional classification of altitudinal belts

Land users in the Ethiopian highlands have traditionally classified their environment in relation to topography. This traditional denomination is a relative one, although it has some absolute characteristics. Early travelers such as Dove as quoted by Pankhurst (1957) described major agricultural zones in Ethiopia as “*Kolla*” (below 1800 m a.s.l.), ”*Weyna Dega*” (1800-2400 m a.s.l.), and ”*Dega*” (above 2400 m a.s.l.). Later, scientists like Hufnagel (1961) confirmed this traditional Ethiopian zonation and added a further zone at higher altitudes called “*Wurch*” (higher than 3800 m a.s.l). Many examples confirm that this classification is relative. In the Semien mountains, a high altitude area in northern Ethiopia with the country’s highest peak *Ras Dejen* (4533 m a.s.l.), farmers who are living at elevations above 3000 m a.s.l. would say that land users below them live in the *Kolla* belt, although these villages are as high up as 2800 m a.s.l. In other parts of the highlands, an altitude of 2800 m a.s.l. would be called *Dega* (Hurni, 1999).

Despite the above flexibility in the traditional altitudinal classification, there are certain characteristics, which most Ethiopian land users would agree to. In the *Wurch* zone, usually no rain-fed crops would be expected to grow. Frost is a frequent phenomenon, and afro-alpine grasslands are the dominant land cover if the altitude is not too high even for these perennial or annual grasses. In the *Dega* zone usually crops such as barley, wheat, and pulses are grown. However, no tef (*Eragrostis tef*) or maize (*Zea mays*) would be expected in this belt. Within the *Dega*, a differentiation can be made between High *Dega* where only barley (*Hordeum vulgare*) and sometimes potatoes (*Solanum tubersum*) are grown, and a Lower *Dega* or “*Dega proper*” belt, which would additionally allow for wheat (*Triticum aestivum*) and pulses (*Vicia faba, Lens esculenta, Pisum sativum*). But both *Dega* belts are still too cold to produce *tef* or maize. The *Weyna Dega* is the most dominant Ethiopian agricultural belt where all major rain-fed crops can be grown including tef and maize. This is the belt where both agro-climatic as well as ecological conditions are highly suitable for rain-fed farming. The lower part of this belt is also suitable for cash crops such as coffee, tea, different spices, and inset (*Inset ventricosum*), an important staple crop of southwestern and southern Ethiopia. The *Weyna Dega* belt usually has sufficient rainfall allowing at least one cropping season per year. Below this belt is the *Kolla* with moisture limitations for crops such as maize, potatoes, wheat and pulses. Sorghum is dominantly grown in this belt, and if rainfall permits, also *tef* and maize. In the *Kolla* belts of the southern and southwestern parts of the country where rainfall is relatively high and with low temporal and spatial variability, maize is abundantly grown thereby claiming the area to be called the “maize belt” of the country (Tafesse, 1996). In the *Kolla* belt temperatures are higher than the highlands, and there is a higher variability of rainfall resulting in recurring drought conditions. Below the *Kolla* is the *Berha* belt, where normally no rain-fed cultivation is possible. Hot temperatures and persistent drought render the area unsuitable for rain-fed cultivation. Most of the major large-scale irrigation schemes of the country are developed along the river systems in this belt.

3.1.3 Agroecology and agroclimatology

From a scientific point of view, ’ecology’ is the science of the relationship between living organisms and their abiotic environment, and ‘agro-ecology’ particularly relates to agronomic requirements. Another term often used is ‘agro-climatology’, which is the science of long-term weather patterns in relation to agronomic requirements. In most studies in the field of agro-ecology, a major attempt at agro-ecological zonation has been made through the application of agro-climatic models and tools. Although agro-climatology only describes one aspect of agro-ecological zonation, it is the component, which has been well developed (Hurni, 1998). ”Zones” are horizontal spatial units having specific properties (such as agro-ecology). “Belts” on the other hand, are spatial units, which lie between two defined altitudinal boundaries and also have specific properties, similar to the zones.

A number of scientific approaches have been applied in Ethiopia to determine the agro-ecological zones (Hurni, 1998, 1995; Amare, 1980; Westphal, 1975). Apart from the descriptions of traditional altitudinal belts cited above, a number of studies relating to vegetation types and farming systems were carried out by FAO/UNDP (Constable, 1984), Constable (1985) and Amare (1984). Constable (1985) defined the Ethiopian highlands to cover all areas above 1500 m a.s.l., sub-divided into three zones characterized as “low potential cereals zone” (all northern highlands), “high potential cereal zone” (basically Gojam, northwestern Shewa and the Arsi-Hararghe highlands), and ”high potential perennial zone” (southwestern highlands). The “Guidelines for Development Agents on Soil Conservation in Ethiopia” (Hurni, 1985, 1986) provided an agro-climatic classification system for Ethiopia according to altitude and length of growing period. This pragmatic system was used to propose suitable soil and water conservation technologies for these zones, additionally differentiated according to land use, slope, and soil type. This is the most widely distributed and used guideline in the country, which forms a basis for subsequent studies.

Mention should be made of different maps, e.g. the “Agro-ecological Zones of Ethiopia” by NRMRD (1998), the maps of Tafesse (1996) for southwestern Ethiopia, those of Mesfin (1991) for north Shewa and Wello, and “Agro-ecological Belts” (1:1,000,000, Hurni, 1999). These maps that were produced in 1995 and distributed by the Ministry of Agriculture are currently being used to plan watershed management and soil and water conservation activities. The maps represent agro-ecological belts of Ethiopia, i.e. altitudinal zones that can be defined as ‘major agro-ecological zones’ of the country. The spatial distribution of the agro-ecological belts were mapped on a newly compiled topographic basis that was derived from large-scale maps of the Ethiopian Mapping Authority, and that was finally used to develop a new digital elevation model in a geographical information system.

Accordingly, test catchments with traditional land use systems and a size between one and seven km^2 were chosen. Soil erosion and other related variables were monitored in these catchments. The sites were observed for a period of one or more years without SWC, as well as for several years after SWC technologies had been implemented by the World Food Programme (WFP). The SCRP benchmark sites were selected in Maybar / Wello (moist *Weyna Dega* / *Dega*, established 1981), Hunde Lafto / Hararghe (moist *Weyna Dega*, established 1982), Andit Tid / Shewa (moist *Dega* / high *Dega*, established 1982), Anjeni / Gojam (wet Weyna Dega, established 1984), Afdeyu / Eritrea (dry *Weyna Dega* / *Dega*, established 1984), and Dizi / Illubabor (wet *Weyna Dega*, established 1988), another site was taken over from the Wolayta Agricultural Development Unit (WADU) in Gununo / Wolayta (moist *Weyna Dega*, established 1982). For a more detailed description of the sites in Ethiopia refer to Annex 1.

3.2 SCRP research methodology

The SCRP gave emphasis to applied research; hence its research program was implemented on-farm not on-station, with as little disturbance of the catchments and farmers' fields as possible (Figure 3.2). The standard research program focused on monitoring runoff / river discharge and soil loss / sediment yield at different scales, on different slopes and soils, under various crops, land use types, and SWC treatments. Current soil erosion rates were measured on test plots and at a hydrometric station, where hundreds of events were recorded over the years on each site. This allowed determining the average patterns of soil erosion, i.e. meaning annual and monthly results. Extreme patterns of erosion were determined by analyzing the impact of the most severe rainstorms (critical times), and by mapping erosion rills at critical locations right after such extreme erosion periods. Parallel, climatic data such as the amount, erosivity, intensity, inclination and direction of rainfall, air and soil surface temperature, wind direction, evaporation and duration of sunshine were recorded to interpret erosion measurements. Land use was mapped for each cropping season. Throughout the catchments, crop yield and biomass samples were collected regularly to monitor production of the major crops. The general status of soil degradation was determined through soil survey.

In addition to this standard program, the SCRP responded to site-specific research needs with a supplementary program. Population and livestock dynamics, household land management strategies, attitudes towards and perceptions of SWC, effects of agronomic SWC measures, indigenous SWC measures and strategies, soil fertility mapping, erosion modeling, as well as reactions to policy changes were observed in selected sites. The SCRP used a program hierarchy with different research levels (Figure 3.3). At the lower levels, data were collected exclusively by the SCRP itself within its seven research catchments and their surroundings. At higher levels SCRP data were combined with information from other sources, such as the Ethiopian Mapping, Meteorological or Land Use Planning Authorities.

Figure 3.2: Research and implementation (Drawing: Karl Herweg)

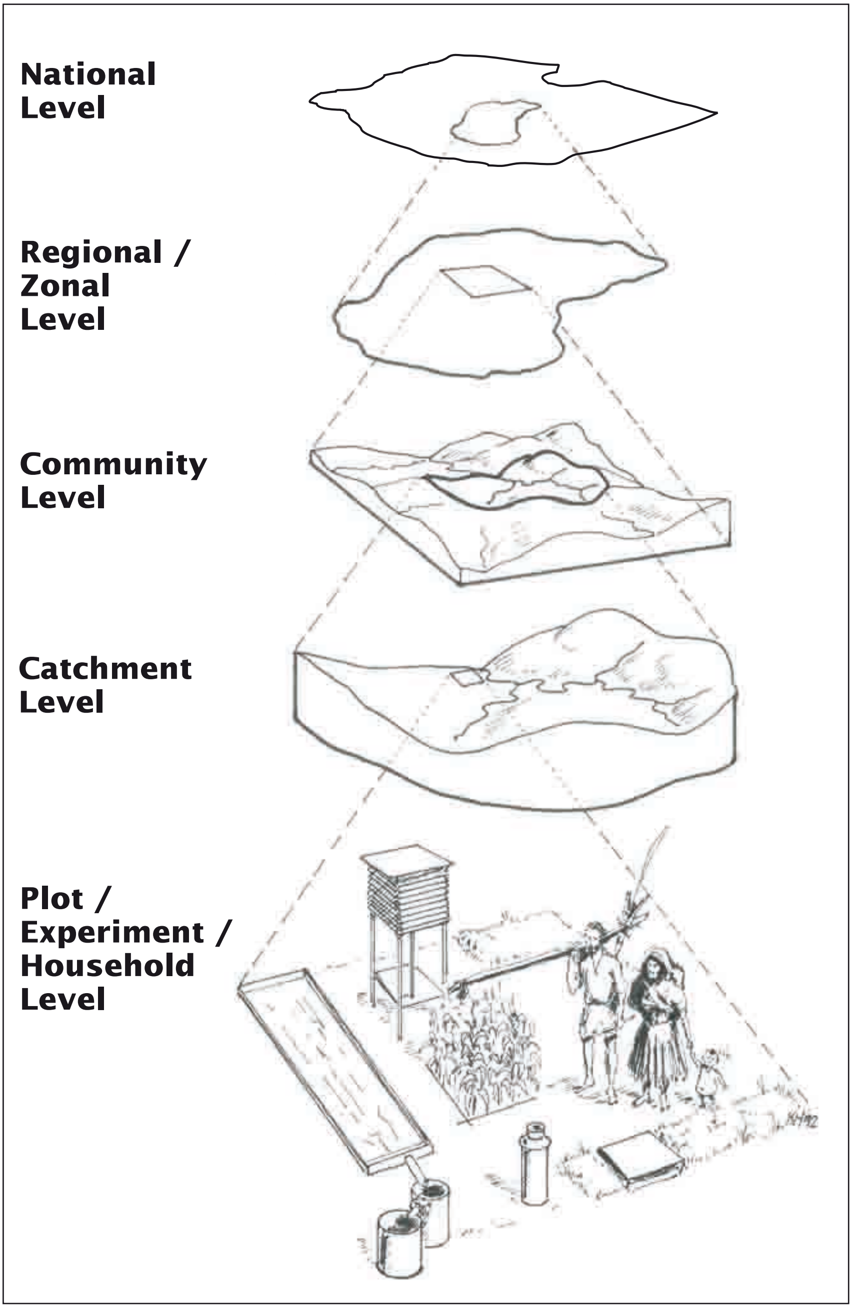


Figure 3.3: SCRP levels of research (Drawing: Karl Herweg)

3.3 Levels of soil erosion measurement – an example

The focus on soil erosion requires the development of a specific erosion measurement methodology which involves data collected on various levels and with different devices, levels of accuracy, possibilities and limitations of interpretation (cf. Table 3.1).

- Rainfall and erosivity are measured for individual rainstorms using an automatic rain gauge located in the vicinity of the river gauging station.
- Close to the rain gauge, each research station maintains four test plots (TP, 2 m x 15 m) and two to four micro-plots (MP, 1 m x 3 m) on which soil loss, runoff, and production data are recorded. The impact of selected SWC techniques (usually grass strip, Fanya Juu, and bund) on soil loss, runoff and production is tested on four to six experimental plots (EP, 6 m x 30 m). All SCRP plots are on-farm plots; the farmer decides the crop rotation and timing of farm operations. The rugged topography involves frequently changing slope angles and soil properties. In addition, farm size is often below one hectare (ha) and a farm is further divided into numerous farm plots. This makes it almost impossible to find comparable plots of homogeneous soil, slope, crop type and farm management and does usually not permit replications of plot measurements. Thus, over the years, each plot represents an average soil loss and runoff "behavior" in a specific situation. Herweg and Ostrowski (1997) investigated the accuracy of plot soil loss and runoff values, as the result of a range of systematic and random data errors, parameter estimation errors, and model errors. For single erosion periods, the error ranges between ±2-5% for runoff and ±6-16% for soil loss, respectively. The error of annual data, in contrast, is lower with ±0.1% for runoff and -3% for soil loss, respectively (cf. Table 3.1).
- River discharge and sediment yield are recorded with gauging stations at the outlet of the research catchments (ranging from 1 to 7 km^2). Bosshart (1996, 1997a, 1997b, 1997c, 1998a, 1998b) provides the methodological background and a detailed analysis of sediment yield and river discharge in selected SCRP stations. The estimated error of sediment yield and river discharge is ± 5 - 10%.
- If rills and gullies are formed, usually during the main erosive events, they are mapped on-farm. This methodology is known as the „Assessment of Current Erosion Damage" (ACED), and has been documented in a field manual by Herweg (1996). The estimated error of rill volume/soil loss (ACED) is ± 15 - 30%.

Table 3.1: Indications, limitations and estimated accuracy of different SCRP soil erosion measurement levels (Source: Herweg and Stillhardt, 1999)

Measurement level	Characteristics and possible interpretation	Limitations on the interpreta-tion of results	Estimated error (± %)	Remarks and source of information
Hydrometric Station ■ sediment yield ■ river discharge	■ *areal measure-ment device*, measuring outflow from a defined catchment; ■ long-term or permanent monitoring device; ■ results indicate possible down-stream pollution (sedimentation) and flood risk	no differentiation of sources of erosion within the catchment possible; **Caution:** unreliable ex-trapolation without knowledge of channel characteristics	*sediment yield and river discharge*: 5 - 10%	original error was estimated to be 1 - 5%, without considering random errors during measurement (Bosshart 1996, 1997a)
Erosion Plots ■ soil loss ■ runoff	■ *point measurement devices*, measuring soil transport over a defined slope length (e.g. a TP represents one average terrace spacing) during rainstorm periods; ■ long-term or permanent monitoring device; ■ results indicate soil erosion rates (mainly sheet and pre-rill erosion) under different soils, slopes, land management practices, SWC technologies, etc.; ■ results underline the importance of severe rainstorm periods	negative balance: TPs consider only soil lost from the area but no deposition gained from upper slopes; narrow plot width encourages entrainment and pre-rill erosion: soil loss rates may thus be overestimated; **Caution:** without appropriate model the extrapolation of results is unreliable	*soil loss*: annual - 3% storm 6 - 16% *runoff* annual 0.1% storm 2 - 5%	accuracy is estimated for erosion plots which are well maintained: e.g. there is no interception of rainfall by canopies of high plants outside the plot; there are no further sinks or sources of sediment and water, etc. inside or outside of the plots (Herweg and Ostrowski 1997)
Assessment of Current Erosion Damage ■ soil loss	■ *point-linear measurement*; measuring rill and gully erosion losses at critical locations during severe rainstorms; ■ short-term monitoring method; ■ results indicate extreme soil erosion rates	**Caution:** no extrapolation possible; data are storm-based, annual data relatively uncertain	*soil loss* 15 - 30%	the accuracy improves with the experience of the observer; while increasing vegetation cover and more complex rill systems increase the chance of error; (Herweg, 1996)

3.4 Management concept and interpretation of SCRP data

The SCRP collects data and information of different kinds, resolution, and accuracy. In order to respond to requests from decision makers, planners, researchers, trainers, students, extension agents etc., such data need to be linked or combined in various ways. In a few cases, such links can be of a quantitative nature. For example, rainfall, runoff and discharge can easily be combined since they are all documented in the same unit (mm). Other data need to be transformed; such as soil loss and sediment yield (from t/ha into mm of topsoil loss) in order to be linked with rill mapping data. More often, however, different types of data cannot be combined quantitatively, but only semi-quantitatively or qualitatively through a combination of measurement, interpretation and judgment. For example, quantitative measurements of biophysical data on EPs can help identify suitable SWC measures. But qualitative information gained from socio-economic surveys regarding the viability and acceptability of SWC is equally important.

The SCRP developed a basic data management concept from data collection in the field to analysis and final interpretation (Figure 3.4). The left side of the figure shows the general data management concept, while the right side indicates examples of the corresponding erosion data management (Herweg and Ostrowski, 1997). High accuracy measurement of soil erosion processes is very labor-intensive and costly. Therefore, before starting to collect data it should be clear for what purpose they will be used, and how accurate the data should be. There are a number of options from basic research to applied erosion research, but in what follows, the focus will be on the application aspect.
Four guiding questions can help identify a suitable research set-up (N.B. that, depending on the aims of research, not all questions may require scientific investigation):

- **Where does soil erosion occur?** Locations with high erosion hazard – the so-called hot spots – can be detected easily through observation and mapping of current and/or past erosion features (rills, gullies, accumulations, etc).
- **When does soil erosion occur?** Concentrating on severe rainstorms with high erosion hazard, information can be obtained from long-term meteorological stations and from interviews with local land users.
- **Why does soil erosion occur?** Answering the first two questions reveals many direct causes or triggers of erosion, but also the indirect reasons of erosion.
- **How much soil is eroded?** Answering this question is usually time and labor-intensive as well as costly. Corresponding methods and devices are of different quality and accuracy. Long-term (permanent) monitoring can be carried out on test plots (representing a farm plot) or river gauging stations (representing a catchment). Short-term methods such as observations and mappings of erosion features need

to be carried out after several rainstorms each year. If there is no way to measure soil erosion directly, mean soil loss rates (erosion hazard) can be estimated using prediction models (USLE, WEPP). The empirical USLE and its derivates do not require many input data, but its results are of uncertain accuracy. WEPP and other physical models deliver better quantitative results but also require high inputs.

Expectations of what research should and can contribute to solving real-life problems are manifold, and not all of them are realistic. The experience of the SCRP shows that practitioners – policy-makers, planners, farmers, etc. – are frequently not in a position to clearly express what their demands are, and also that their demands and questions can change quickly. Furthermore, once a research set up is designed and implemented, its flexibility to take up newly emerging demands and fashions is limited. In practice this means that on-going research can provide only part of the answers or solutions required. In addition, it is usually not only one measurement that responds to a specific demand, but rather a combination of quantitative and qualitative data sources. Figure 3.5 shows the most common links of measurements and observations with assessments and interpretations that have practical relevance. Some of the assessments and interpretations are useful to design protective and productive SWC measures together with farmers, others assist planners and decision-makers in developing supportive activities at the regional or national levels, such as to identify priority areas for SWC, design legislative measures, and the like.

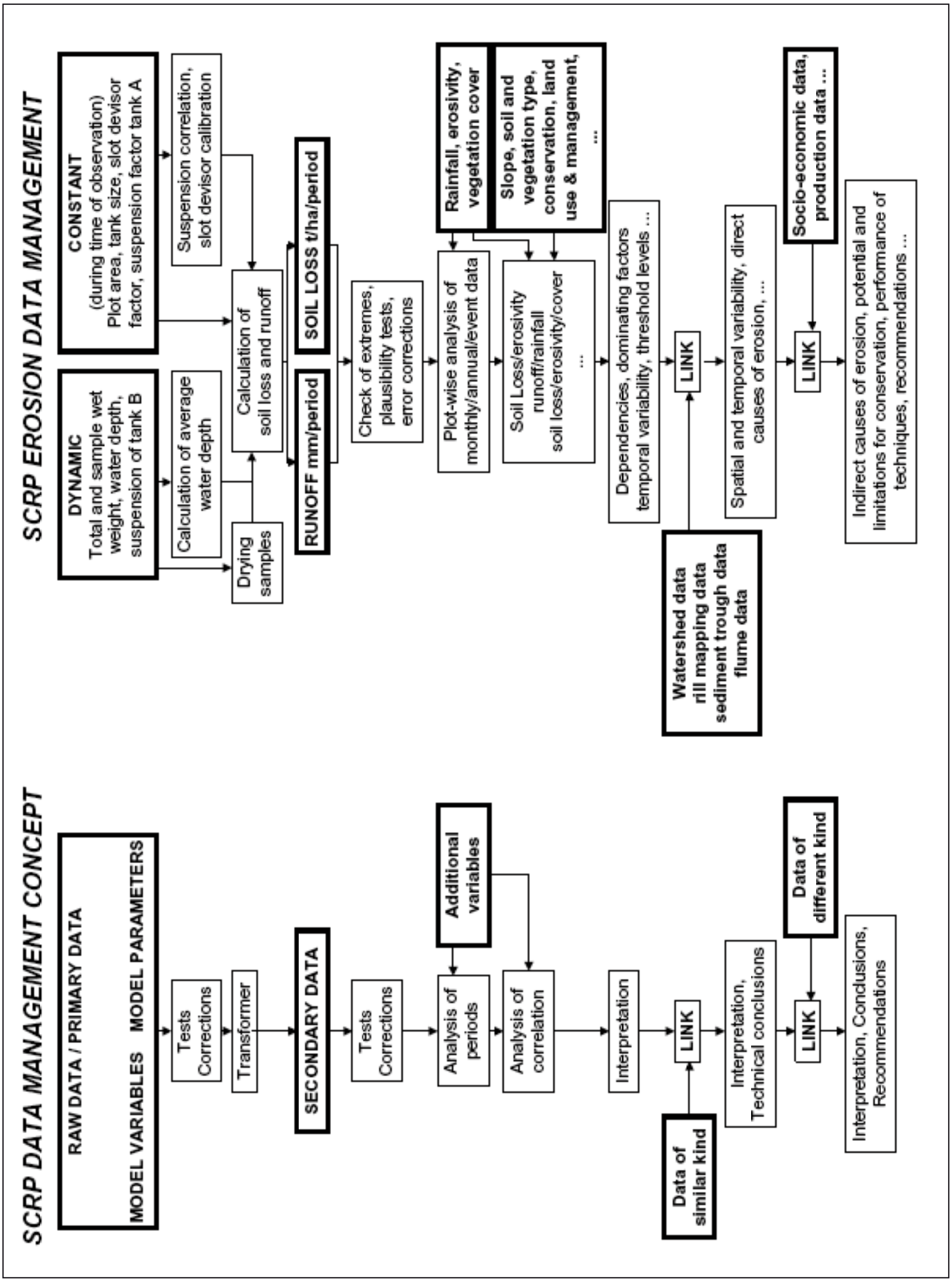


Figure 3.4: SCRP data management concept (Source: Herweg and Ostrowski, 1997)

Primary or raw data are divided into two parts. The dynamic part contains all measurements of variables made during each erosion event, while the constant part describes parameters *which are not supposed to change, at least not within one cropping season or year. Some of the parameters require a particular estimation procedure, such as slot divisor calibration or derivation of the sediment concentration in suspension. All field data, including average calculations of water depth, estimated parameters, and laboratory data are entered into the main transformer, in this case the plot soil loss/runoff calculation formula. The results of the calculation – output data of the test plot measurements – are considered secondary data (t/ha of soil loss, mm of runoff). They can be used as input data for a model (algorithm) of a higher order, passing through a series of tests (extremes, plausibility, error, etc) before they appear as monthly or annual time series for each plot.*

Soil loss and runoff can be linked (e.g. correlated) with additional variables, such as rainfall, erosivity, and vegetation cover, allowing initial interpretation of the temporal variability of soil erosion. Then other parameters such as slope gradient, soil type, type and cover of vegetation, land use and land management, soil conservation practices, etc., can be considered in another correlation analysis, leading to an interpretation of interrelations, dependencies, causes, and effects of factors related to soil erosion. At the next stage, plot results can be linked with data of a similar kind from other levels of erosion measurement, such as gauging stations, sediment troughs, and assessment of current erosion damage (ACED, rill mapping). In this way, spatial and temporal variability, average and extreme patterns, as well as several direct causes of erosion can be assessed. It is then possible to draw certain "technical" conclusions, e.g. regarding the timing of SWC activities and critical locations that require special attention, what plant cover is necessary for effective soil protection, hazardous land use and land management. etc. Eventually though, erosion data must be linked in qualitative or semi quantitative manner with data of a different kind which describe the socio-economic, political, and cultural framework under which peasants implement SWC. Technical information about the impart of SWC measures on soil erosion is meaningless when it comes to implementation, unless it is supplemented by an analysis of the economic viability and cultural adaptability of SWC measures, for example.

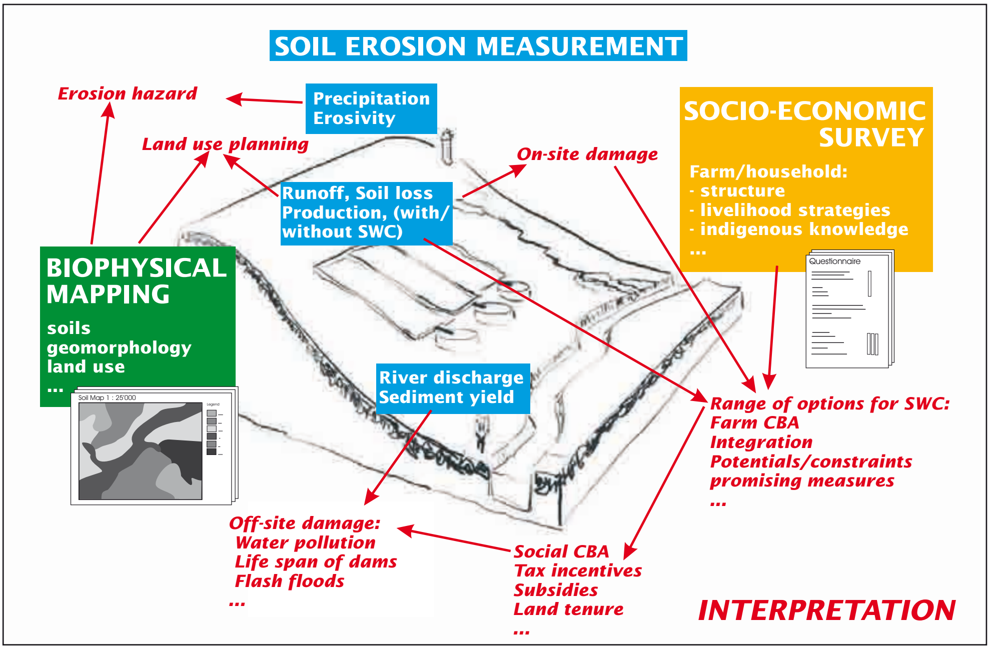


Figure 3.5: Measurement, survey mapping and interpretation (Drawing: Karl Herweg)

3.5 Questions and issues for debate

- There is no standard research methodology for soil erosion and conservation research; the set-up of measurement levels and devices rather depends on the purpose of measurement. What research methodology would you design:
  - a) to monitor the effects of soil and water conservation technologies, i.e. to estimate how well they control soil erosion, if they are economically viable, and if they are socially acceptable?
  - b) to develop an algorithm predicting the order of magnitude of soil erosion under various soil, slope, vegetative and land use conditions?
- In section 3.4 it was pointed out that research mostly delivers only part of the information that would be needed to answer a practical question or to solve a real-life problem. Then, who do you think will provide the remaining part of the answers or the solutions?
- Give critical comments on the suitability of the traditional agro-ecological zonation in Ethiopia with regard to distribution of livestock.

4 Average Soil Erosion Patterns under Different Agro-Climatic Conditions

Soil erosion is frequently quantified as soil loss from a given area over a specific period of time. It is expressed in standard units, usually tones per hectare and year (t/ha·y), as if net soil loss is independent of the size of the measured area (Nyssen et al., 2003b; Van Noordwijk et. al., 1998), which in reality is not the case. Although widely used, the term "soil loss" is slightly misguiding and requires some attention. Tanks at the lower end of a test plot collect soil that is washed from (and thus "lost" for) this plot area. What is not considered is that, on regular farm land without plot borders, the "soil in the tank" would be re-deposited somewhere further down, while at the same time this plot area would gain some sediment that was eroded upslope. River sediment yield values measured at most research sites suggest that a considerable part of the soil eroded on the slopes does not reach the river. However, great amounts of eroded soil are deposited in unfavorable positions, such as wet valley floors, along field borders, on footpaths, etc., where they are of little use for food production. Although not lost from the catchment, a lot of soil is lost for agricultural production.

Annual runoff and soil loss rates, computed from test plot measurements, are the most widely used values to underline the severity of on-site erosion problems and to emphasize the need for SWC. Similarly, annual river discharge and sediment yield values indicate potential off-site effects. In turn, low annual soil loss values are used as an indicator of a successful SWC. It is important to notice, though, that the magnitude of soil loss depends on the degradation processes taking place and thus to a great extent on the measurement devices and plot sizes used (cf. Figure 4.5 and Table 4.3). Therefore, data cannot be appropriately interpreted without knowing the measurement devices or models that generated them. Direct measurement of soil erosion rates is rather rare because it involves high costs and time inputs. Many reports have thus to rely on quoting primary and secondary literature, often without mentioning the methodology corresponding to the data, let alone the measurement accuracy. As a result, there is a great potential of data misappropriation. Particularly further statistical analysis of data taken from unknown sources can be critical, and the consequences of inappropriate decisions based on such analysis will finally be borne by the farmers, not the writers!

Therefore, it is important to reflect the possibilities and limitations of interpreting mean annual values or annual sums. Examples from the database of the Soil Conservation Research Program (Herweg and Stillhardt, 1999) will help clarify what can be concluded from which data and what not. For example, mean annual overview figures (As described in this chapter) can be important for decision-makers and planners who need to know where SWC priorities should be established, or more generally, where to intensify agricultural development. Such average erosion rates, however, tell very little about what type of SWC technology could be implemented to alleviate the problem (Figure 4.1). More detailed information on the temporal and spatial distribution of erosion events, and particularly on the extreme events, is necessary to design appropriate SWC measures (Chapter 5).

When interpreting the data it is important to note that test plots are located in different agro-ecological zones, on different slopes and soil types with different crop rotations. The duration of measurement differs as well from site to site. Therefore, comparison of the data has to be made with care! Nonetheless, a combined interpretation of annual and monthly plot data provides good insight into the orders of magnitude of soil erosion and its variability in the highlands.

Figure 4.1: Model and reality

A model that is based on annual values provides a general overview of the spatial distribution of a parameter. But it will most likely not match the reality on a specific farmers' field. Therefore, it may not be realistic to design specific SWC measures at the micro level on the basis of annual data with coarse spatial resolution! (Drawing: Karl Herweg)

4.1 Temporal resolution I: mean annual data

Figure 4.2 and Table 4.1 present mean annual data for seven SCRP research stations. The upper bar chart of Figure 4.2 contains the mean annual **rainfall and erosivity**; starting from the left hand side with the lowest mean annual rainfall (Afdeyu) to the right hand side with the highest mean annual rainfall (Anjeni). In general, mean annual rainfall erosivity is also increasing from left to right, although not as strongly as the rainfall amounts. The centre bar chart contains the **mean annual runoff** from two cultivated test plots and one grass test plot (2 m x 15 m), as well as the **mean annual river discharge** measured at the river gauge; the lower bar chart contains the **mean annual soil loss** from two cultivated test plots and one grass plot, as well as the **mean annual sediment yield** measured at the river gauge. Before interpreting Figure 4.2, it could be interesting to cover the centre and lower bar charts and formulate on the basis of the only climatic parameters what runoff and soil loss values would be expected.

4.1.1 General interpretation

Areas of high on-site soil erosion rates

The highest soil erosion rates were measured in sub-humid areas with less variable high rainfall and intensive cultivation (Anjeni, Andit Tid, Gununo). Being close to the climatic limit of agriculture above 3000 m a.s.l., vegetation growth at high altitude locations such as in Andit Tid (Northern Shewa) is reduced, slopes are steep and even average erosion rates can be extremely high. Despite similar magnitudes of rainfall and erosivity, areas like Gununo (Welayta), in contrast, with great biodiversity, better ground cover and gentler slopes show lower soil loss values. Such environment permits a more intensive land management involving vegetative conservation measures and buffer strips that prevent sediment eroded on the cultivated areas from reaching the river. Grain basket areas like Anjeni (Gojam) have highest percentages of cultivated area and thus, in combination with high rainfall and erosivity, the greatest soil losses.

Areas of low on-site erosion rates

In the humid, high-rainfall areas of the western highlands (Dizi, Illubabor), intense and quick vegetation growth to a large extent prevents soil erosion. In these areas, nutrient leaching is the limiting factor for long-term cultivation. A shortened fallow period with more intensive farming can therefore increase soil erosion.

Areas where high off-site damage is expected

Hunde Lafto and Maybar show high sediment yield and concentration. This is due, on the one hand, to rainfall of sufficient quantity to cause erosion, but also to high rainfall variability that limits the development of permanent vegetation along the riverbank. On the other hand, soils in these two catchments are prone to severe riverbank and gully erosion. The high sediment yield of Anjeni, in contrast, is to a great extent the result of intensive crop cultivation and downslope drainage ditches. For all three areas, sedimentation of reservoirs and water pollution could be the subsequent off-site problems.

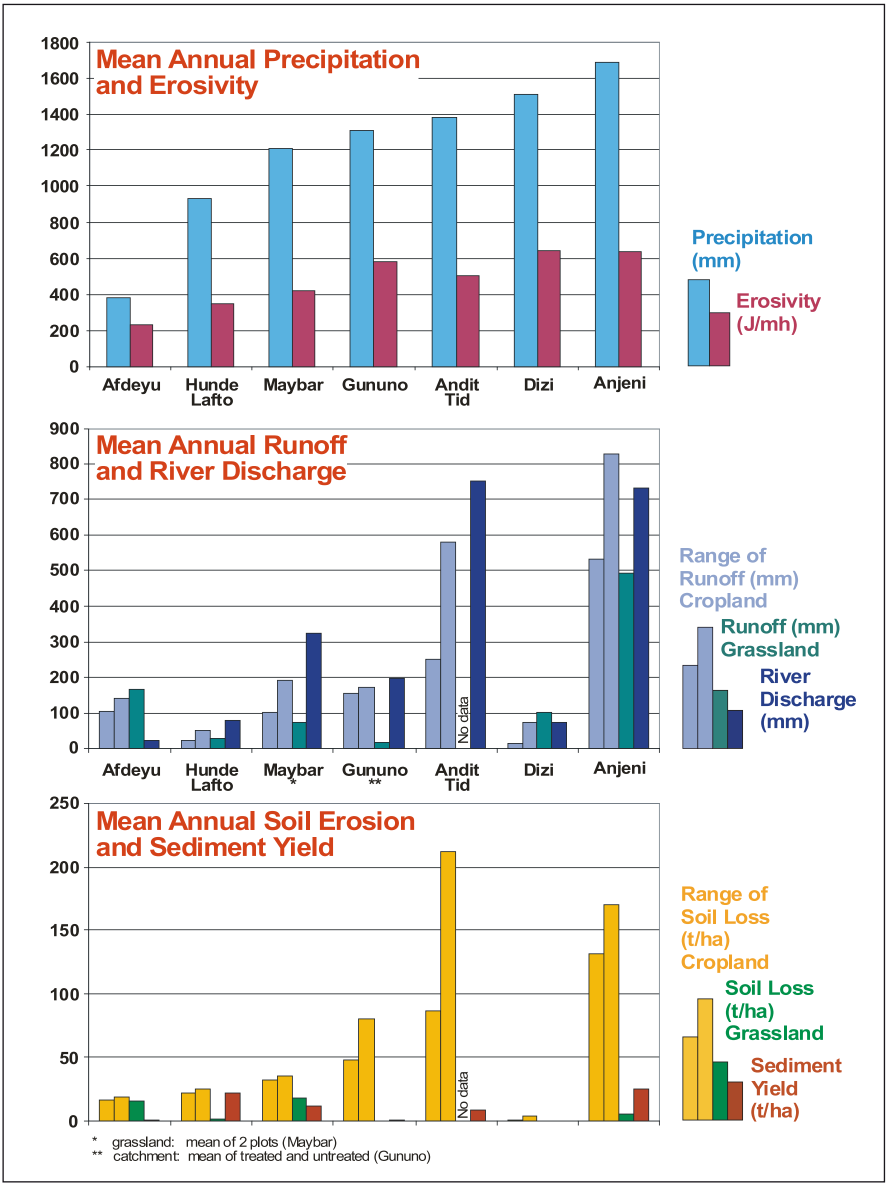


Figure 4.2: Mean annual climatic and soil erosion parameters of seven SCRP research sites

Table 4.1: *Mean annual climatic and soil erosion parameters of seven SCRP research sites*

		Semi-arid → high rainfall variability							**Sub-humid low rainfall variability**
Agro-climatic zone		Dry *Weyna Dega / Dega*	Moist *Weyna Dega*	Moist *Weyna Dega / Dega*	Moist *Weyna Dega*		Moist *Dega / High Dega*	Wet *Weyna Dega*	Wet *Weyna Dega*
Research site		*Afdeyu*	*Hunde Lafto*	*Maybar*	*Gununo*		*Andit Tid*	*Dizi*	*Anjeni*
Years of observation		*1985-1990*	*1983-1993*	*1982-1993*	*1982-1992*		*1983-1992*	*1989-1993*	*1985-1993*
Climatic values									
Rainfall	mm	382	935	1,211	1,314		1,379	1,512	1,690
Erosivity	J/m·h	233	346	420	582		506	646	633
Cultivated test plot values									
Runoff	mm	105-141	23-49	103-191	156-171		252-581	14-74	533-828
Runoff	%	28-38	3-5	9-16	12-13		18-42	1-5	31-49
Soil loss	t/ha	17-19	22-25	32-36	48-80		87-212	1-4	131-170
Catchment values					*no SWC*	*SWC*		*no SWC*	
River discharge	mm	21	80	324	246	149	754	73	731
River discharge	%	6	9	27	19	11	55	5	43
Sediment yield	t/ha	0.8	22	12	0.7	0.1	9	0.002	25

N.B. The above values are means rounded after calculation.
Annual values are based exclusively on years with complete measurements for all months; years with interruptions in measurement (due to war and security problems) are excluded. In contrast, monthly means contain the measurements for all months, even if the year was not monitored completely (Source: Herweg and Stillhardt, 1999)

Areas where no off-site damage is expected
Sediment yield is lowest, as expected, in Dizi and Gununo, due to dense permanent land cover. However, the indiscriminate removal of vegetation can cause unprecended soil erosion with consequent off-site effects.

Variability of annual values
In all stations, annual rainfall shows the lowest coefficient of variation (CV), from 0.08 to 0.29 (Table 4.2). Annual erosivity is more variable with a CV between 0.21 and 0.53. The highest climatic variability occurs at Afdeyu and Hunde Lafto, the stations with the lowest rainfall. In contrast to the climatic parameters, annual runoff varies with a CV between 0.12 and 1.21, and annual soil loss much more with a CV between 0.22 and 2.19.

Table 4.2: Coefficient of variation (CV) of important annual values

	Afdeyu	Hunde Lafto	Maybar	Andit Tid	Gununo	Anjeni	Dizi
Rainfall	0.29	0.22	0.20	0.18	0.19	0.09	0.08
Erosivity	0.53	0.47	0.23	0.37	0.34	0.21	0.26
TP runoff	0.56-1.21	0.74-1.16	0.65-0.96	0.27-0.41	0.38-0.65	0.12-0.28	0.19-0.37
TP soil loss	0.53-1.29	0.97-1.89	0.82-1.77	0.25-0.66	0.69-2.19	0.22-1.21	0.95-2.00
River discharge	0.84	1.29	0.37	0.45	0.64 U* 0.75 T*	0.10	0.23
Sediment yield	0.96	1.72	0.68	0.37	1.39 U* 1.46 T*	0.64	0.33

* Gununo paired catchment: U = untreated Goppo catchment; T = treated Zerwa catchment
(Source: Herweg and Stillhardt, 1999)

4.1.2 Site-specific interpretation

Connotations such as “very high”, “high”, “low”, “very low” and the like are relative terms that reflect the comparison of the SCRP research sites among each other.

Afdeyu
The highlands of Eritrea receive the lowest rainfall and have the lowest erosivity measured in the SCRP sites. With high coefficients of variation (CV, see Table 4.2) of annual rainfall (0.29), soil erosion becomes highly variable as well and crop production very insecure. 28 to 38% of the annual rainfall leaves the cultivated test plots as runoff, but only 6% of the annual rainfall leaves the catchment as river discharge. This difference is a result of both infiltration, refill of the groundwater aquifer, and evapotranspiration. On the slopes, structural SWC measures help reduce runoff and

enhance moisture conservation for plant production. In the riverbed itself, farmers have dug a number of holes to fetch water for small-scale irrigation during the dry season. These holes also trap suspended sediment, which, together with well-developed vegetation cover in the flat valley floor can explain the relatively low sediment yield values during the rainy season. The months of highest erosion risk are July, August and – to a lesser extent – September, with a few erosive phases resulting in soil losses measured on test plots of 17 - 19 t/ha·y. Due to the long dry season, soil erosion on the "grass" test plot is not significantly different from the one measured on cultivated plots.

Hunde Lafto

Annual rainfall and annual erosivity are moderate in Hunde Lafto but show a high variability from year to year. On plots, only 3 to 5% of the annual rainfall leaves a field as runoff, while discharge at catchment level accounts for 9% of the annual rainfall. Consequently, soil losses on plots are relatively low (22 to 25 t/ha·y) and sediment yield in the river is comparatively high (22 t/ha·y). However, the variation in annual sediment yield is also high (see able 4.2), and its mean annual value seems distorted by extreme gully erosion and landslides in the riverbed that occurred during a few years, which may cause considerable off-site effects of erosion. Sediment concentration observed both on test plots (45 to 101 g/l) and in the river (50.7 g/l) is very high. Two to three highly erosive phases, usually at the beginning of the rainy season, trigger most of the soil loss.

Under difficult ecological conditions, such as steep slopes and insecure rainfall, the farmers of Hunde Lafto have adapted many SWC measures. For example, farmers maintained selected terraces from the Food-for Work campaigns in the 1980s and supplemented them with trash lines of sorghum straw. These trash lines trap eroded soil particles like structural measures, but they are more flexible, easier to maintain, and less costly. They can quickly be removed and rebuilt wherever necessary. In some spots between two SWC structures, sweet potatoes are grown with a system of dense ridges and furrows that help retain water.

Maybar

With high rainfall and moderate erosivity, precipitation data show a relatively high CV of annual rainfall (0.20) for Maybar, compared to other sites. Only 9 to 16% of the rain leaves the plots as runoff, and 27% leaves the catchment as river discharge. Soil losses on plots (32 to 36 t/ha·y) and sediment yield from the catchment (12 t/ha·y) can be considered moderate and occur usually during a short but erosive phase at the beginning of both rainy seasons. High stone cover in large parts of the catchment encourages diffuse accumulation, and soils seem to be rather resistant to entrainment (robust soil aggregates with a high content of organic material). As in Hunde Lafto, the mean annual sediment yield value is influenced by high gully erosion and landslides in the riverbed occurring during a few years, which bears a considerable potential of off-site damage. In the 1980s, the steep slopes in the centre were treated with area closure, which has almost vanished now.

Andit Tid

High rainfall and erosivity result in very high runoff (18-42% of annual rainfall) and river discharge (55% of annual rainfall) in Andit Tid. Andit Tid is located above 3000 m a.s.l., where low temperatures limit vegetation growth. With a combination of high rainfall, high erosivity and steep slopes, Andit Tid is prone to severe erosion. Considerable entrainment can already be observed on slopes of 15 m length, which account for a large part of the area treated with *Fanya Juu* terraces. Soil losses on test plots range from 87 to 212 t/ha·y. Continuously from July to September, Andit Tid typically goes through many erosive phases in close sequence, with a few extraordinary events at the beginning and towards the end of the rainy season. Experimental plot data reveal that much of the eroded soil is deposited along a narrow strip above the SWC structures. It seems virtually impossible to develop SWC that is technically feasible, ecologically sound, economically viable and socially acceptable at the same time. Thus considerable amounts of soil are still being transported over a long distance in the dense drainage system of SWC (Herweg and Ludi, 1999), underlining a certain potential for off-site damage in this area.

Gununo

Annual rainfall in Gununo is comparable to that in Andit Tid, and erosivity is higher. But since plant growth is not limited by moisture stress and temperature, both high evaporation and infiltration reduce surface runoff and river discharge. In most years, good vegetation cover leads to diffuse accumulation of eroded soil and prevents long distance transport. This is indicated by the micro plot data, which show higher soil loss values than the longer TP in most years. However, when annual erosivity exceeds 750 J/m·h, the conditions are reversed and entrainment dominates. Soil loss is measured during a sequence of moderately erosive phases interrupted by single periods of high erosion, often at the beginning of the rainy season, but also towards the end. Erosion can occur from March to October, with a little less in June, and a peak in August. The riverbanks are densely forested and thus retain most of the eroded soil. Both in the treated and in the untreated catchment, the average sediment yield remains below 1 t/ha·y.

Traditionally, Welayta is one of the most densely populated areas in Ethiopia. Being more familiar with scarce natural resources, farmers have thus established a highly complex and intensive land management system over the centuries. Although erosion can be high on the cultivated fields, vegetation buffer strips in-between or along the steep flanks of the valley floor largely prevent soil transport over a long distance. The structural SWC introduced in the 1980s have meanwhile been adapted to the system. They are being planted with Ensete and grass, and supplemented by traditional drainage ditches.

Anjeni

Anjeni receives the highest annual rainfall of all SCRP stations and is characterized by very high erosivity. As in Andit Tid, runoff (31 to 49% of rainfall) and river discharge (43% of rainfall) are also very high in Anjeni, partly due to climatic conditions, partly due to the intense cultivation in the catchment. The area is thus prone to severe erosion. Test plot soil loss values of 131 to 170 t/ha·y are recorded, indicating considerable entrainment and soil movement between the SWC structures. Like Andit Tid, Anjeni has many erosive phases in close sequence from June to September, with a few extraordinary phases at the beginning and towards the end of the rainy season. Structural conservation can reduce these amounts, but annual values recorded on experimental plots are still at or above 30 t/ha·y. Through the relatively dense SWC drainage system consisting of cut-off drains, terrace channels and waterways, much of the runoff and suspended sediment reaches the river, which suggests considerable potential off-site effects such as flash floods and sedimentation of water reservoirs.

Reliable high rainfall in a unimodal regime, fertile soils, and a rolling landscape make Gojam the high-potential grain basket of Ethiopia. As a consequence, and due to increasing population pressure, a tremendous proportion of the land is cultivated. The remaining grazing area on the valley floor and around the ridges and hilltops is not sufficient to produce fodder for a dense livestock population. Therefore, open grazing is common after harvest, which is a great obstacle to keeping structural SWC in shape.

Dizi

Despite very high rainfall and erosivity, Dizi has the lowest runoff and river discharge of all stations. Both values are around or below 5% of the annual rainfall. Deeply weathered soils and dense plant cover with a good rooting system allow most water to infiltrate. In addition, evaporation is high. The TP soil loss values are also the lowest measured (1 to 4 t/ha·y). High rainfall and temperatures allow rapid development of plant cover at the onset of the rains. Usually in August or September, there is a short period of one or two weeks when the soil is left bare and unprotected. Whatever small amounts of eroded soil reach the river are deposited or trapped on the swampy valley floor, so that the mean annual sediment yield is only 0.002 t/ha·y.

Very heavy rainfall and deeply weathered soils cause a tremendous nutrient leaching problem. Fallow periods of more than 40 years were necessary for soils to recover from five to seven years of cultivation. With the resettlement of farmers coming from the drought-prone parts of Ethiopia, the area is subjected to high population pressure. To accommodate the settlers, huge forests were cleared and even the steepest slopes cultivated with tef and maize. Rapidly growing weeds prevent the soil from severe soil erosion, but are a major obstacle to food production. In addition, guarding the fields from wild animals, takes much of the labor force from the farming community.

4.2 Temporal resolution II: mean monthly data

The high variability of annual soil loss values – even on the same slope and soil – results from a changing constellation of factors, of which the dominant ones are rainfall, erosivity, soils and vegetation cover. It is possible that this constellation is not always critical but can become particularly hazardous only in single years, single months or even single rainfall periods, which may then entirely distort the annual mean. Thus, interpretation of annual results should always be supported by interpretations of shorter resolutions. For example, the analyses on the basis of months (Chapter 4.2) and an even higher resolution (Chapter 5) reveal not only times of increased erosion hazard, but also the difficulties to predict such critical times.

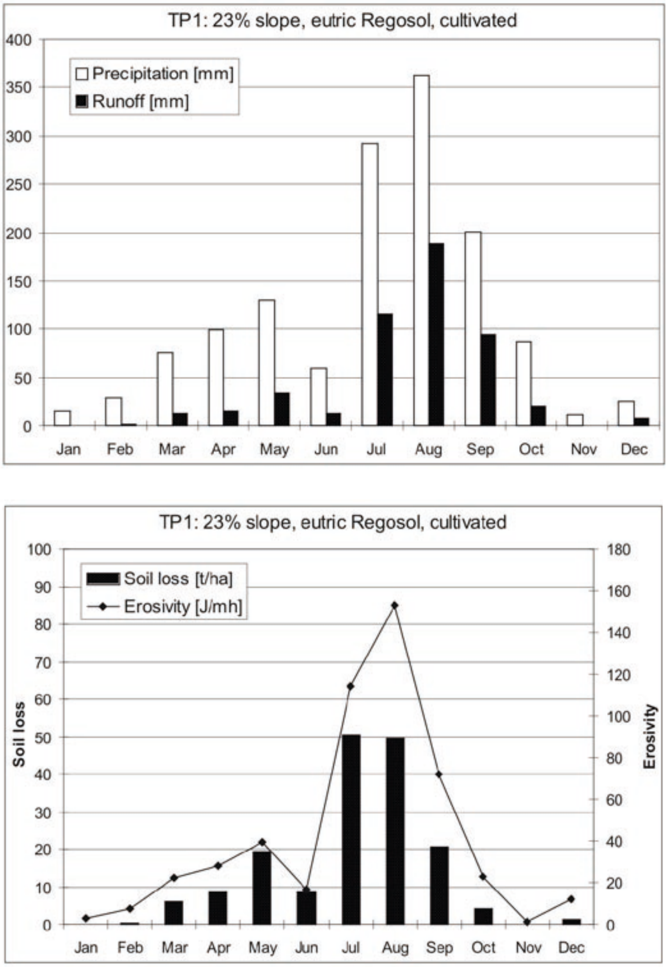
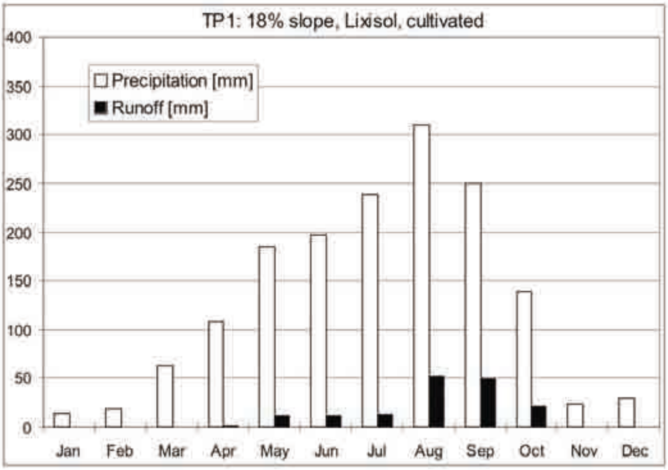


Figure 4.3: Mean monthly rainfall, runoff, soil loss and erosivity measured in ***Andit Tid*** *(1982 – 1992; mean annual rainfall: 1379 mm; mean annual erosivity: 506 J/m·h) (Source: SCRP, 2000)*



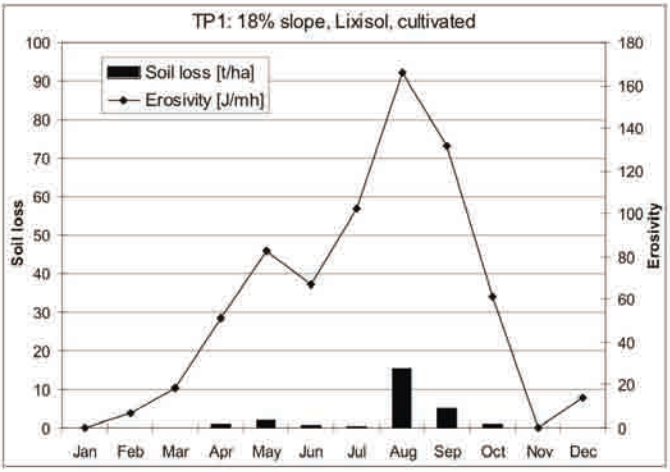


Figure 4.4: Mean monthly rainfall, runoff, soil loss and erosivity measured in ***Dizi*** *(1988 – 1993; mean annual rainfall: 1512 mm; mean annual erosivity: 646 J/m·h) (Source: SCRP, 2000)*

Figures 4.3 and 4.4 show examples of mean monthly test plot data of two stations Andit Tid and Dizi. In both sites, the months of highest erosion hazard – indicated by the months of highest rainfall and erosivity – correspond in general to the months of highest actual erosion – indicated by the months of highest runoff and soil loss. Despite a similar erosion risk or hazard (rainfall, erosivity), the actual erosion (runoff, soil loss) in Dizi is much lower than in Andit Tid. Only knowledge of the site-specificities allows a proper interpretation, i.e. the dense vegetation cover and better infiltration of the soils in Dizi are highly effective in controlling soil erosion.

4.3 Spatial differentiation I: the influence of plot length and steepness on erosion

The SCRP research set-up includes test plots of different size and length. The size of the plot determines what combination of erosion processes will take place (Table 4.3), which consequently leads to a variability of erosion rates measured:

- Micro-plots (MP; length 3 m, width 1 m): no rills were observed on MPs, indicating that this length does not permit the shear velocity necessary to form rills. The soil loss measured consists of material detached by rain splash and entrainment of the sheet flow. MP results represent the amount of soil that is moved on an interrill erosion area.
- Test plots (TP; length 15 m, width 2 m): besides rain splash and sheet flow, prerills a few cm deep were observed on test plots. At the same time, diffuse accumulations of eroded material may occur, which partly refill the prerills. The TP situation represents, for example, the erosion on a terrace between two SWC structures, such as a soil bund or *Fanya Juu*.
- Experimental plots (EP; length 30 m, width 6 m): on the eroded part, rain splash, sheet flow, prerill and rill erosion may occur. On the deposition part, not only diffuse accumulations but also concentrated accumulations are found above the SWC structures. In contrast to TP, the EP represent a situation with a sequence of terraces and SWC structures interrupting both runoff and soil transport.
- The assessment of current erosion damage (ACED) considers exclusively linear erosion features, such as prerills, rills, and gullies, as well as concentrated deposits.
- The sediment yield measured with **hydrometric devices** (river gauging station) at the outlet of a catchment is the result of all water erosion processes taking place in the catchment, including the erosion of the riverbed itself.

Table 4.3: Soil erosion measurement levels and soil degradation processes

Level/ Device	**Soil degradation processes**						
	Erosion					**Deposition**	
	Rain-splash	Sheet flow	Prerill erosion	Rill erosion	Gully erosion	Diffuse accumulation	Concentrated accumulation
MP	frequently observed	frequently observed	rarely observed			frequently observed	
TP	frequently observed	frequently observed	frequently observed	rarely observed		frequently observed	
EP	frequently observed	frequently observed	frequently observed	frequently observed		frequently observed	frequently observed
ACED			frequently observed	frequently observed	rarely observed		frequently observed
Catchment	frequently observed	frequently observed	frequently observed	frequently observed	frequently observed	frequently observed	frequently observed

frequently observed *rarely observed* *(Source: Herweg and Stillhardt, 1999)*

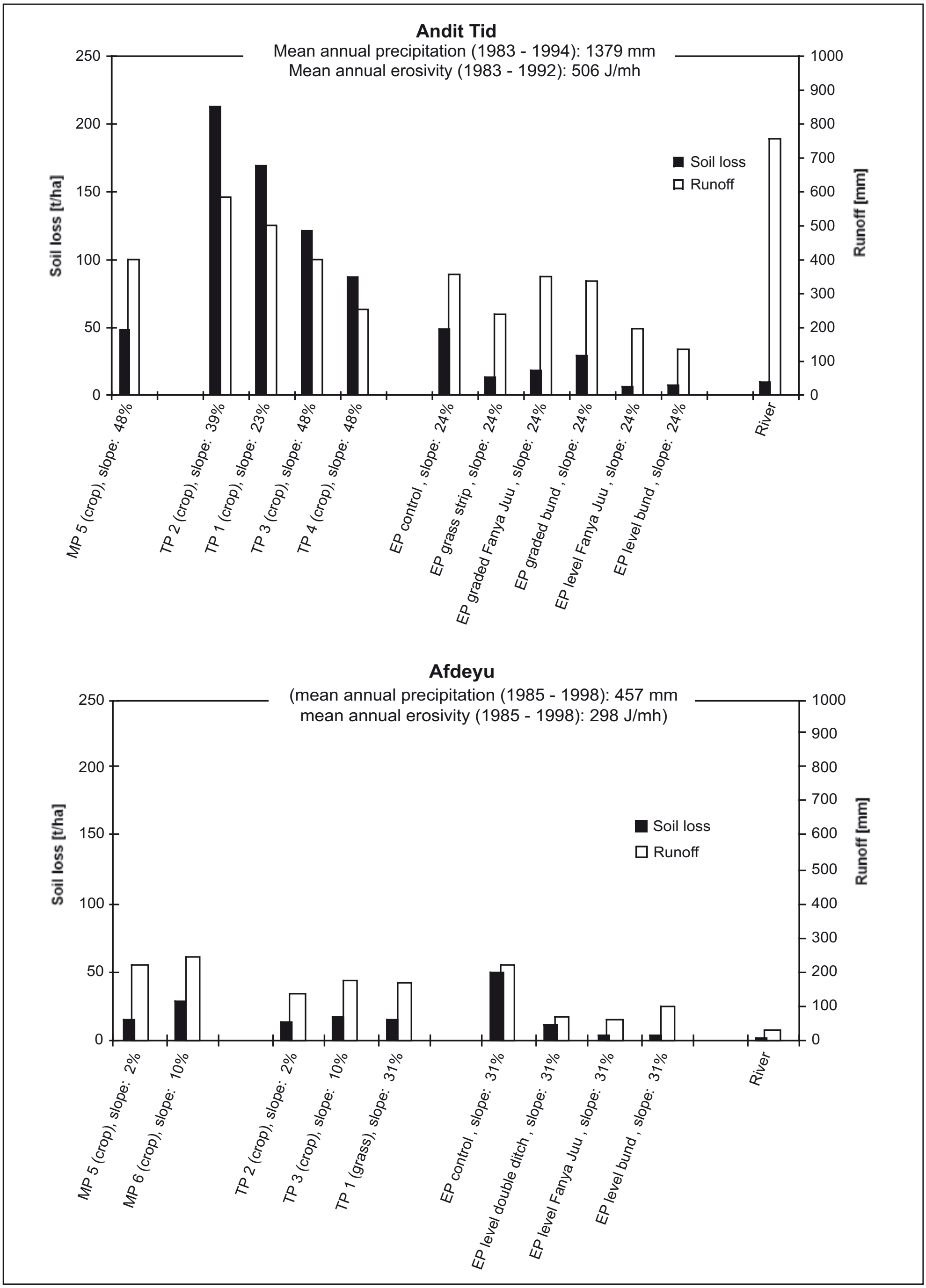


Figure 4.5: Mean annual soil erosion measured with different devices
(Sources: Herweg and Stillhardt, 1999; Stillhardt et al., 2002)

Figure 4.5 shows mean annual soil loss and runoff measured on different levels in two sites, Afdeyu and Andit Tid. A careful comparison of results shows that the relationship between slope length and soil/sediment loss is not necessarily linear (Van Noordwijk et al., 1998). For example, in some stations (example Andit Tid), TP soil loss values (on 15 m slope length) are always higher, and in other stations (example Afdeyu) always lower than MP values (on 3 m slope length). In some cases these relationships change from year to year or even from storm period to storm period. The differences between these two plot types indicate changes of different factors, such as infiltration or vegetation type and cover. We suggest the following interpretation:

- TP value > MP value (soil loss increases with slope length) indicates an increase of erosion due to entrainment and prerill erosion, for example, on bare soils under seedbed preparation. This can be an indication of detachment-limited conditions if runoff does not increase at the same time (Van Noordwijk et al., 1998).
- TP value = MP value (soil loss does not increases with slope length) or
- TP value < MP value (soil loss decreases with slope length) indicates that there is no significant entrainment effect. Under transport-limited conditions soil loss mainly originates from rain splash and is re-deposited in diffuse accumulations. For example, this is the case if infiltration is high due to soil management, texture, structure or rooting, or if ground cover enforces accumulation.

The influence of slope steepness on soil erosion needs also special consideration. The results observed in many SCRP research stations confirm that soil erosion increases with steepness. However, as other factors such as soil type, stoniness, vegetation, etc. vary, the relationship becomes more complicated. For example, in Maybar and Andit Tid, lower soil loss rates were recorded on steeper slopes, because more stony soils allow more infiltration.

4.4 Questions and issues for debate

- 42 t/ha·y is frequently quoted as the average soil loss rate for the Ethiopian highlands. Considering the high variability of soil erosion values measured in different agro climatic zones, what does this average value tell you? What conclusions can you draw based on this value?
- As a decision-maker or extension agent at the regional level, what can you conclude and what interventions could you propose on the basis of the mean annual and mean monthly soil erosion values?

5 Extreme Soil Erosion Patterns

In contrast to the "average behavior" of soil erosion – expressed by annual data on rainfall, erosivity, soil loss, and runoff – the 'extreme" patterns of erosion provide more detailed information about two aspects. (1) The **temporal aspect** refers to the variability or irregularity of soil erosion events within a year, focusing on heavy rainstorms that trigger high soil losses. (2) The **spatial aspect** is concerned with critical locations – the so-called "hotspots" – along a slope section that are visibly damaged mainly by rill and gully erosion processes.

5.1 Temporal resolution III: the irregularity of rainstorm periods

Studies by Hagmann (1996) in Zimbabwe, Edwards and Owens (1991) in Ohio (USA), Chromec et al. (1989) in Hawaii, Schaub and Prasuhn (1993) in Switzerland, and Herweg (1988a, 1988b) in Tuscany (Italy) state that a large proportion of annual soil loss occurs during a few rainstorm periods. Provided this is so, the effectiveness of a SWC measure depends on the extent to which it can resist such „extreme" rainstorm periods. Therefore, insight into such periods provides better information for SWC technology development at the field level than mean values.

To rely on average soil erosion data (t/ha·y) can be tempting to believe that soil erosion is evenly distributed throughout time and space. However, only a few heavy rainstorms usually cause the bulk of annual soil losses. Then, the state and cover of the vegetation is an important factor that determines whether or not a rainstorm period causes severe erosion. The literature evaluates the protective function of vegetation cover differently. On the one hand, Stocking (1998) mentions that erosion decreases drastically to about 10% when vegetation exceeds a ground cover of 40%. He reveals that the interactive process between soil and plants is sufficient to cope with erosion, provided that, depending on the crop type, vegetation is maintained at levels above 50 and 60% plant cover. Hudson (1995) reports similar findings. Both authors refer primarily to studies in Zimbabwe. Young (1989) assumes that a ground surface litter cover of 60%, maintained throughout the period of erosive rains, will normally reduce erosion to lower and acceptable levels, even without additional structures of the barrier type. Herweg (1988a) observed drastically decreasing erosion in Tuscany, Italy, if cover exceeded a 50% threshold. On the other hand Cyr et al. (1995) argue that cover must be at least 70% during erosive rains in the Quebec Appalachians. Thomas (1991) qualitatively states that during heavy rainfall, vegetation cover is not too effective in controlling erosion in the southeastern highlands of Ethiopia. It appears that the first group of authors is referring to „average" conditions, while the second group considers „extreme" conditions.

The analysis of SCRP data by Herweg and Stillhardt (1999) reveals that annual erosion rates are heavily dominated by single rainfall periods as can be observed in Table 5.1. The occurrence of such periods is highly erratic, which explains the high variability of annual results (cf. Chapter 4). High soil losses result from a combination of many factors, for example, high erosivity, low vegetation cover, steep slopes and high soil moisture. Herweg and Stillhardt (1999) report that, on average, for all cultivated plots at all stations:

- 5% of the annual rainstorm periods caused 30% of the annual sediment yield and 45% of the annual soil loss.
- 20% of the annual rainstorm periods caused 64% of the annual sediment yield and 84% of the annual soil loss.

In exceptional years, a single rainfall period may cause 60% or more of the annual soil loss, for example in a semi-arid environment such as Afdeyu with a generally lower number of rainstorms per year.

Table 5.1: The impact of rainfall periods on annual soil erosion values

% of annual...	**Afdeyu (17 - 20 t/ ha*y)**				**Hunde Lafto (22-25 t/ha*y)**				**Maybar (32 - 36 t/ha*y)**			
...rainfall periods	5 %	10 %	15 %	20 %	5 %	10 %	15 %	20 %	5 %	10 %	15 %	20 %
...precipitation	10.0	19.6	27.1	37.2	8.6	15.9	19.9	31.8	9.4	17.4	23.2	28.5
...erosivity	12.2	23.5	43.3	45.7	17.2	31.2	39.2	52.5	17.3	36.1	41.2	42.7
...runoff	10.0	22.2	54.3		32.0	53.3	61.5		27.8	45.7	55.8	62.1
...soil loss	26.5	51.6	70.5	83.0	61.4	79.9	85.7	94.2	48.0	75.9	84.5	89.6
...river discharge	6.4	15.4	42.8		9.4	17.4	32.8	38.0	12.5	24.3	31.6	35.7
...river sediment load	11.6	22.5	49.4		18.6	29.9	37.6	41.6	41.6	60.3	67.2	72.0
Number of rainfall periods	(6)	(5)	(8)	(3)	(18)	(15)	(9)	(9)	(16)	(18)	(17)	(14)

% of annual...	**Andit Tid (86-212 t/ha*y)**				**Gununo (48 - 80 t/ha*y)**				**Anjeni (131 - 170 t/ha*y)**			
...rainfall periods	5 %	10 %	15 %	20 %	5 %	10 %	15 %	20 %	5 %	10 %	15 %	20 %
...precipitation	12.4	21.9	29.3	36.7	10.1	18.0	25.3	31.8	11.8	19.2	26.3	32.3
...erosivity	24.7	39.8	48.7	57.0	23.2	35.1	46.6	54.9	25.8	36.9	45.4	52.0
...runoff	20.7	34.7	44.8	54.4	25.9	44.5	57.3	67.6	21.1	31.0	42.8	51.5
...soil loss	38.4	55.9	66.0	74.8	49.3	70.4	81.2	87.7	37.1	52.8	64.6	72.9
...river discharge	8.4	15.9	22.4	29.8	6.7	12.6	24.4	29.0	8.2	11.4	16.6	21.5
...river sediment load	36.5	52.0	59.7	66.6	32.4	47.4	71.4	79.9	24.3	35.3	44.6	53.1
Number of rainfall periods	(39)	(39)	(39)	(39)	(22)	(16)	(18)	(22)	(25)	(23)	(24)	(24)

% of annual...	**Dizi (1 - 4 t/ha*y)**				**Average of all stations**			
...rainfall periods	5 %	10 %	15 %	20 %	5 %	10 %	15 %	20 %
...precipitation	14.3	24.7	31.6	41.9	11.1	19.5	26.8	34.0
...erosivity	20.8	37.6	46.7	62.7	21.8	35.9	46.7	54.7
...runoff	20.5	32.4	40.0	52.7	23.4	38.4	48.3	56.2
...soil loss	78.3	89.8	95.6	97.2	44.7	63.7	76.8	84.2
...river discharge	9.8	16.2	20.2	26.3	8.7	16.1	25.9	29.2
...river sediment load	31.2	58.6	69.4	75.3	29.7	45.2	57.8	64.2
Number of rainfall periods	(6)	(6)	(6)	(6)	(132)	(123)	(119)	(117)

Notes:

Afdeyu (17-20 t/ha*y) Station (range of mean annual soil loss on cultivated plots)
Blanks: Insufficient data

(Source: Herweg and Stillhardt, 1999)

A specific constellation of factors to trigger high soil losses is a high erosivity rainstorm that occurs during times of low vegetation cover. Usually, the probability of such coincidence is highest at the beginning of a rainy season, when fields are freshly plowed. Immediately after harvest, in contrast, there is mostly sufficient ground cover available to provide protection. Open grazing, however, can contribute to reducing stubble cover after harvest up to the stage of exposing the bare soil. Considering these two factors of influence on soil loss, rainfall erosivity and vegetation cover, SCRP data reveal that under low plant cover (0 - 30%), which is usually found during the onset of rains, to moderate plant cover (30 - 60%), all storm periods actually can cause erosion. The 100 periods producing the highest soil losses recorded in all stations (with a range of soil loss from 30 to 85 t/ha per period) all occurred under low vegetation cover at the beginning of the cropping seasons. The erosivity of these storms was exceptional (> 100 J/m·h), extreme (> 50 – 100 J/m·h) and very high (> 30 – 50 J/m·h). Such high erosivity periods caused about 20% of the total soil loss recorded. Periods with low (< 10 J/m·h) and moderate erosivity (10 - 20 J/m·h), which accounted for about 70% of all analyzed events, made up around 40% of the total soil loss recorded. Under high plant cover (> 60%), only periods of extreme (> 50 – 100 J/m·h) and exceptional erosivity (> 100 J/m·h) caused a few but high soil losses. For example, soil losses of 10 to 20 t/ha were measured in a rainstorm period under 65% vegetation cover, and up to 5 t/ha in a rainstorm period under 75 to 85% cover. It is important to keep in mind that these measurements were made under test plot conditions, implying that, due to the corrugated iron sheet borders of the plots, runon from outside was basically excluded. On “regular” cultivated fields with runon, erosion damage may as well be worse!

5.2 Spatial differentiation II: hot spots of erosion

Micro and test plot data represent the average rain-splash, sheet flow and pre-rill erosion, balanced to a certain extent by diffuse and concentrated accumulations. Such balance implies a rather slow down-slope movement of soil particles step-by-step, rain after rain. From the analysis above it becomes clear that the bulk of a given annual soil loss value occurs during only 20% of the annual rainstorms. Similar to its uneven temporal distribution, the spatial patterns of soil erosion are also irregular, i.e. that only a part of a given cropland is actually contributing to the bulk of soil loss. Those parts of an area that are seriously affected are called “hot spots”. Visible erosion features, such as rills, gullies and concentrated accumulations, often indicate hot spots. Rill erosion, compared to sheet erosion, has an entirely different character. It removes a considerable amount of topsoil and it creates transport conduits for both water and soil (Nyssen et al., 2003a; Bryan, 1987) originating from the rain splash and sheet wash of the inter-rill areas. Through rills, eroded particles are transported quickly over a large distance. Large particles are more effectively transported. Rills and gullies are embryo drainage systems, which will develop eventually into badlands if unchecked. This may involve irreversibility of the land to put it back into crop production in agricultural systems that are based on animal-drawn implements for cultivating the land, which is the case, in most of the agro-ecological zones.

According to Hurni (1988b) and Nyssen et al. (2003a), obvious signs of erosion such as gullies and rills might hinder or aggravate land management operations for farming. In particular current features indicate that tolerable amounts of soil loss must have recently been exceeded, even if the rills are small. According to Hagmann (1996), rill damage has a major impact because it reduces the area of production. It is possible that erosion may have a positive impact, for instance if it removes exhausted topsoil layers or if it causes reasonable accumulation of fertile layers on top of infertile soils. However, in most cases the disadvantages of erosion will dominate.

Several authors describe rill erosion damage in the African context. Hagmann (1996) from Zimbabwe and Nyssen et al. (2000b) from Ethiopia report that the major causes of rill erosion damage were related to influx of water from outside, non-effective contour ridges and drains, and concentration of runoff from within the field. In Lesotho, Wenner (1989) found that many large rills and gullies on terraces were due to level terracing, and he refrains from advocating this measure. Von Gunten (1993) and Thomas (1991) come to similar conclusions presenting detailed lists of rill erosion damage and its causes in Ethiopia. Regarding frequency of occurrence, Thomas (1991) concludes for Hunde Lafto that land management predominates over natural factors, triggering 81% of all cases of rill erosion damage. Defective and poorly maintained soil and water conservation structures alone are responsible for 36% of the damage observed in the study area. Also Hagmann (1996) reports SWC failure to be a major cause of severe rill erosion in Zimbabwe.

Such failures in soil and water conservation structures suggest that more detailed information is required for appropriate design of structures, particularly where runon and erosion occur, what type of measure is needed, and exactly where. But this would imply that each field is continuously “monitored” over time – a task that can only be done by the land users themselves. If SWC is established on the basis of average erosion rates, assuming a homogenous erosion process, it will face several technical problems at locations where extreme erosion manifestations such as rills and gullies occur.

Since both the factors triggering and steering severe erosion, and the order of magnitude of the resulting damage are highly site-specific and variable, generalization has to be made with care. An idealized pattern of the spatial aspect is the erosion topo-sequence that describes the “hot spots” of erosion damage along a topographic sequence of a slope (Figure 5.1). This can be a short checklist supported by a sketch or photo (cf. Photos 5.1 – 5.3) that help for example extension agents to search for possible signs of erosion damage, causes and effects (Herweg, 1996). The erosion topo-sequence contains obvious damage and direct cause-effect relationships. Asking why erosion occurred at a certain hot spot will also uncover the hidden reasons for unsustainable land management within the socio-economic framework. For example, a soil and water conservation structure broke and changed the flow of surface water, which resulted in severe erosion damage. Such an event does not only indicate the need to improve the design of the structure, but even more importantly, to ask what went wrong in the first place. Did the structure break because the detrimental impact of an open grazing system on SWC structures was forgotten and not considered as an impediment while designing and planning the conservation measures? Did farmers stop maintaining structures after incentives were discontinued? Were extension workers inexperienced in soil and water conservation design? Answering such questions points to potential improvements which could pave the way for establishing more efficient soil and water conservation technologies, e.g. participatory planning, careful use of incentives, or better training and capacity building.

5.2.1 Assessment of current erosion damage (ACED)

The method “Assessment of current erosion damage” (ACED) is based on the work of Schmidt (1979), which was further developed by Seiler (1983), Rohrer (1985), Vavruch (1988) and Schaub (1989) in Switzerland. For Mediterranean conditions, it was adapted in Italy (Herweg, 1987) and for tropical conditions in Ethiopia (Herweg, 1992b). Million (1992), Berhanu (1991), Thomas (1991) and Von Gunten (1993) tested ACED in various studies in the Ethiopian highlands. ACED was developed for two purposes. One is to supplement existing erosion measurement levels such as test plots and river gauging stations. The other is to provide practitioners with a more cost-effective tool to assess soil erosion and draw conclusion about implementation of SWC. Therefore, the ACED methodology has been separately published as a field manual (Herweg, 1996). The following analysis is based on several years of soil erosion damage mapping in the research stations of Andit Tid, Hunde Lafto, Gununo and Maybar. It is published in Herweg and Stillhardt (1999).

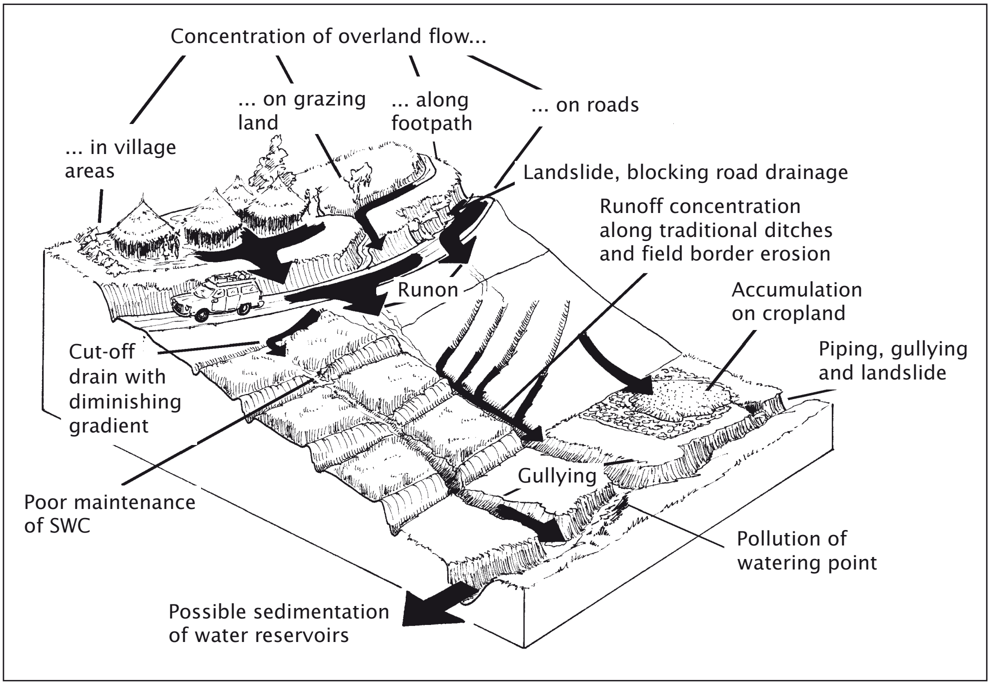


Figure 5.1: Erosion topo-sequence

*ACED is carried out in three steps after erosive storms, starting with the visible erosion features. The first step is to measure the volumes of the erosion features and the land management unit where they occur, in the so-called **damaged area**. Erosion damage may occur particularly on cultivated fields or other areas that are partly left without vegetation cover. Erosion features can often be linked to causes located on the damaged field itself, e.g. on steep slopes with high runoff velocity, in depressions and on long slopes with high runoff concentration, on silt soils and on soils with low organic matter with high erodibility, on fields which are plowed up and down slope, etc.*

*The second step is to investigate the **upslope** area in view of its contribution to the features. The sources of runoff may be found outside the areas with actual erosion damage, i.e. above or upslope of the damaged area. Commonly, runoff is created on areas of low infiltration, such as the sealed surfaces of settlements, roads, footpaths and animal tracks. Interestingly, also grass and bush-land, which have a much better infiltration, can "produce" considerable runon if overland flow from these areas is not well drained. It is one of the most dangerous sources of erosion down slope. Where does runon enter the damaged field, and where is it generated (along roads, small depressions or catchments, etc.)? The relevant answers to these questions can only be found if the mapping staff is in the field during a rainfall event!*

*The third step is to document the subsequent impact of the erosion features on the **downslope** area. Damaged areas can easily create consequent damage on the areas down slope. For example, the eroded material accumulates and buries plants and seedlings, or blocks roads and pollutes settlements. Field border erosion (gully) is a commonly observed phenomenon in humid areas where fields have to be drained. These gullies may also extend and destroy infrastructure such as roads or villages. Eventually, sediment that reaches the rivers can affect water quality and may lead to sedimentation of irrigation dams, while increased runoff can cause flooding or flash floods, a danger for downstream settlements (Drawing: Karl Herweg).*

Photo 5.1: Runon, rill erosion and accumulation

Rills as an indicator of considerable topsoil loss and long distance transportation often occur in slope depressions, alternating with accumulations on concave foot slopes (in the foreground). In this example, the very low vegetation cover shortly after germination has fostered the erosion process. However, the rill originates almost at the upper field border, which means that the conditions of the damaged field alone, such as vegetation cover, slope, soil, etc., cannot be the only reason for the rill. Overland flow in the upper parts of the slope was collected behind the stonewall that can be seen in the centre, a traditional conservation measure used by Italian smallholder farmers. Finally, concentrated flow broke the wall and caused the damage below. This phenomenon of overland flow entering a cultivated field is called "runon". It underlines the fact that SWC should not focus on cropland only but needs to encompass the entire slope (Photo: Karl Herweg 1987).

Photo 5.2: Footpath and soil erosion

The photo shows a footpath crossing crop and pasture land on a relatively steep slope in Kembata. At several points there is indication of beginning gully erosion above the path (covered by grass), and a combination of landslips and advanced gullying along the path and in the field above (right hand margin of the photo). Overland flow that concentrated along the path has merged with flow within the gullies above, and has created damage on the field below while entering as runon (Photo: Karl Herweg 1990).

Photo 5.3: Roadside gully

A frequently observed phenomenon is gullies that develop parallel to roads, particularly when the road is crossing a slope depression or valley. The factors contributing to that incident are manifold. The road itself and the village in the background of the photo build a compacted surface that does not permit infiltration. Such sealed area is a source of tremendous overland flow. People and animals use the area adjacent to the road as "sidewalks" and thus add to the compaction of the soils. The drainage of the cropland also contributes to the concentration of overland flow. The role of the little Eucalyptus plantation on the right hand side is unclear and should be clarified. Were the trees planted to stop gully erosion, or has the gully below developed because of the plantation (keeping in mind that densely planted Eucalyptus trees and uncontrolled grazing and collecting firewood prevents the establishment of ground cover)? (Photo: Karl Herweg 1988).

Being a rough method, ACED cannot have the same accuracy as test plot or gauging station measurements (Herweg, 1996). Mapping of volumes and the number of rills and gullies can be carried out with an accuracy of ± 15%, but it may decline to ± 30% or more with inexperienced observers. The quantitative results become more inaccurate if vegetation cover and the number of rills increase, or if the form of the rills becomes more complex (Herweg, 1996). In contrast to controlled experiments under test plot conditions, the number of factors influencing rill and gully development varies considerably. Individual factors can produce drastic changes, particularly where „runon" occurs. A footpath or a defective cut-off drain, for example, can tremendously increase or shrink the catchment of a rill or gully. Concentration of runoff behind SWC structures, which is basically one of the desired effects of controlling erosion, can turn into a detrimental effect and create rills and gullies if the structure is poorly designed or if it is destroyed by grazing cattle. It is thus impossible to repeat rill measurements, both in time and space. However, as an important and often dominant part of erosion reality, these factors should not be ignored.

The results of ACED are indicative and helpful for improving SWC implementation. But they are not statistically significant, because it is hardly possible to carry out the mappings after each rainstorm. The sample considered only fields with rills and gullies, and did not include fields without damage. Therefore, the results do not represent an entire slope or a catchment, but only its critical locations. Consequently, certain patterns of damage may be over-represented, and a qualitative and semi-quantitative analysis is appropriate.

5.2.2 ACED case studies in selected research sites

Order of magnitude

ACED was mainly carried out in Andit Tid, Hunde Lafto, Gununo and Maybar. Considering all the rills and gullies mapped, the huge variation in the quantitative results reflects the variety of factors potentially influencing rill development (Figure 5.2). The results do not show normal (Gaussian) distribution, and the sample size is too low to postulate normal distribution. Therefore, arithmetic mean and standard deviation are not used; instead, median, minimum, maximum and the quartiles give an overview of the distribution of extreme damage.

- In half of the observations, less than 10% of the entire cropland was actually damaged. However, in 10% of all observations, rills and gullies covered more than 30% of the area. About 3% of the observations revealed a damage affecting more than 70% of the field concerned. The maximum areal coverage of rill damage observed was 90%.
- In half of the observations, the absolute amount of soil lost from the erosion channels themselves exceeded 4 t. In about 10% of the observations it was above 50 t, and in about 4% of the observations above 150 t. The highest absolute soil losses measured were 841 t and 1’621 t, respectively. N.B. that the values discussed here are not annual values but were mapped during single rainfall periods!
- The area that is covered by rills and gullies undergoes serious topsoil loss. The minimum removal observed was 20 mm. It was above 120 mm in half of the observations, above 400 mm in about 5% of the observations, and reached a maximum of 1,670 mm.

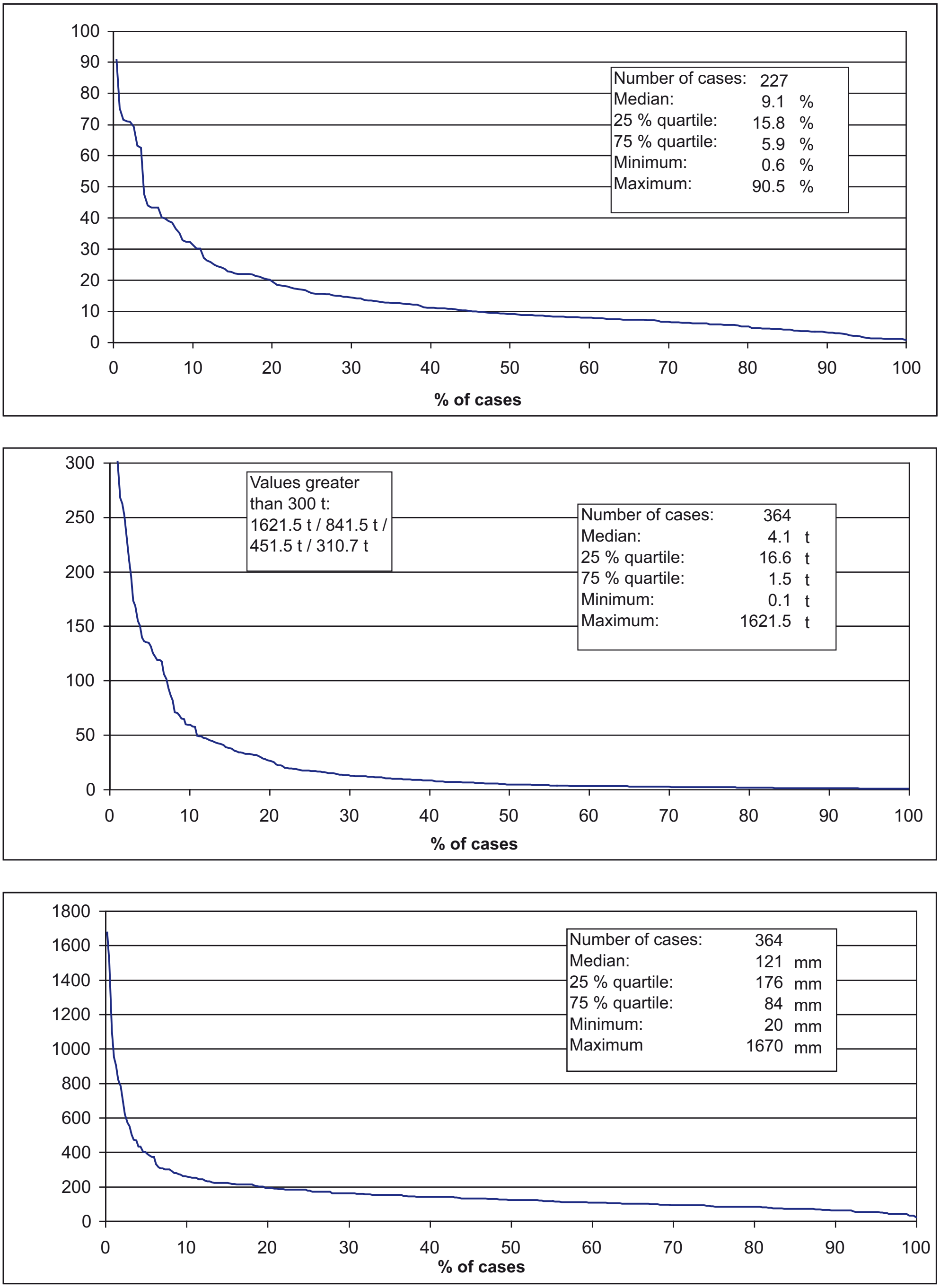


Figure 5.2: The order of magnitude of rill erosion damage
(Source: Herweg and Stillhardt, 1999)

Important influencing factors on the damaged area

Land use and vegetation

Erosion damage usually occurs on cropland and on short-term fallow land that is under grazing.

- During seedbed preparation (0 cover) and under low cover (< 30%), high rill damage is frequently observed.
- Under medium cover (30 - 60%) less damage is observed. However, this may also be due to the lack of mapping during this stage of plant growth.
- Under high cover (60% and 70%) some cases of considerable rill damage were mapped. The highest soil losses were related to mixed cropping (sorghum / maize / haricot beans in Hunde Lafto; sorghum / maize and maize / sweet potato in Gununo; beans / barley in Andit Tid; beans / peas / lentil in Maybar). This may occur at a stage when cereals already provide protection from rain splash, but the immediate ground cover of the pulses is not yet developed. Rill erosion under high plant cover mostly relates to runon caused by parameters located outside the field under consideration.
- Except for Maybar, fields with cereals seem generally more susceptible to rill erosion than those with pulses.
- The ground cover of fallow land, particularly under open and uncontrolled grazing as it is practiced in Andit Tid and Maybar, does not provide sufficient protection.

Soils and slope

The mappings selectively consider only fields where rills and gullies occurred. Since there is no area coverage of the mappings, no conclusion can be made about which soil types or textures might be more susceptible to rill erosion. Runoff concentration and rill erosion were observed on all soils, including those considered having basically good drainage. Similarly, rills were observed in all slope classes and on all slope shapes. From the available data it cannot be concluded that, for instance, flat slopes are less susceptible to rill erosion, or that the highest soil losses occur along depressions. The impact of differences in soil properties and slope characteristics on rill erosion may also be outweighed by the impact of land management and conservation factors.

Land management/soil and water conservation

Andit Tid, Hunde Lafto and Maybar are catchments treated with SWC measures. Gununo consists of one catchment under SWC and one untreated catchment. Surprisingly, in Gununo the highest rill erosion losses were observed on fields within the treated catchment. Also, the data from other stations suggest that SWC often contributes to erosion instead of preventing it.

- Rills commonly develop where the gradients of cut-off drains diminish. This led to the extreme soil loss observed in Hunde Lafto.

- he collapse of SWC structures such as terraces is the most frequently observed case of SWC failure in Andit Tid, Hunde Lafto and Maybar. The collapse may be due to poor design of SWC, lack of maintenance, openly grazing livestock, concentration of rodents, or the rejection of farmers. At the point of collapse, water is diverted through the structure and easily reaches a concentration that creates rills and affects downslope SWC structures.
- Waterways are subject to incision on steep slopes. If they cannot accommodate high runoff volumes during severe rainstorms, surface water is diverted to cultivated fields where it creates rills. This was observed especially in Andit Tid.
- Traditional drainage ditches caused considerable rill erosion in Andit Tid and Maybar. If their gradient is too low or diminishing (cf. failure of cut-off drains), accumulations block the channel and runoff is diverted. If ditches are too steep, they cause incision (cf. failure of waterways).

Important influencing factors on the upslope area

Of a total of 648 observations of erosion features made at four stations, only 4% (all observed in Andit Tid) did not show the influence of runon, which underlines the particular importance of this factor in the entire slope section. In addition, it stresses the need for an efficient and comprehensive drainage system (Hagmann 1996). Bearing in mind that test plot measurements exclude runon, it is obvious that damage mapping is an important supplement in erosion methodology, particularly to improve the design of SWC. Runon can result from various sources located upslope, which contribute to a concentration of overland flow that consequently breaks onto cultivated fields. When several factors simultaneously contribute to runon, it is usually not possible to determine the impact of a single factor. In the analysis, the respective soil loss value was divided proportionally among the contributing factors, and so the results have rather indicative character! In general:

- Rill erosion rates are high if areas with sealed soil surface such as footpaths, animal tracks, roads and settlements, etc. contribute to runon. During the Ethiopian villagization program, the number of footpaths increased in order to connect the new villages to the old fields in the surroundings. Nowadays, without proper drainage, these are a major cause of erosion.
- Other major areas of origin for runon are upslope cultivated fields, fallow and overgrazed pastureland, particularly where SWC structures are not maintained or broken down.
- It is surprising to see that rills are frequently associated with runon from vegetated upslope areas such as grass or bush land. Vegetated areas themselves are well protected, but the overland flow they „produce“ may still be sufficient to cause erosion downslope.

Beyond these general conclusions, SWC must respond to site-specific problems in order to be effective and efficient:

- In Andit Tid, village areas, fallow areas, and cultivated areas with defective waterways deserve special attention.
- In Gununo, despite the high frequency of runon originating from cultivated fields, no serious rill damage was measured. But tremendous rill and gully erosion can be observed along roads, paths and villages outside the research catchment.
- In Hunde Lafto, the drainage of footpaths, villages, grassland and cultivated land should be improved to reduce erosion on-site.
- In Maybar, a road, grassland, bush land and cultivated land create runon problems and require an effective drainage system.

As indicated earlier, controlling erosion is to a large extent a matter of controlling the drainage of an entire slope, not only the cultivated area. Only a properly designed and maintained drainage system of cut-off drains, terrace channels and waterways will be able to minimize erosion during times of low vegetation cover. It is therefore necessary to involve groups or communities of land users in the design and maintenance of the drainage system. Soil erosion is not only a consequence of intensive agriculture, but also of other land use factors such as settlements and roads. Thus, erosion problems can only be solved when farmers, planners, engineers and others work together.

Subsequent erosion damage on the downslope area

After mapping the damaged area and the influence of the area upslope, further signs of soil erosion may also be observed downslope. This subsequent damage is expressed in terms of frequencies of cases observed.

- Rill and gully erosion does not necessarily stop at the field border. It may create subsequent damage, such as erosion and accumulation on cultivated fields downslope. The accumulation of fertile topsoil as such may improve the fertility of the field that receives it. Often, however, infertile subsoil is deposited downslope, or deep accumulations bury germinated plants.
- Field border erosion results from runoff concentration and can easily develop into gullies that hamper farming operations and require special treatment. This usually involves high costs and labor input once the gullies are established.
- The damage to grassland along valley floors is another frequently observed phenomenon that may harm fodder and animal production.
- Rills and gullies, often results of piping, serve as transport channels and thus contribute to river pollution and decline of water quality.
- Footpaths, villages and other infrastructure are easily damaged or polluted by rill and gully erosion.

In addition to these cases observed on-site, other types of subsequent damage may occur off-site, for example, pollution of watering points. There is also a high probability of sedimentation of water reservoirs below areas with intense riverbank erosion such as Hunde Lafto, Maybar and Anjeni.

5.2.3 Linking ACED with test plot measurements

In contrast to long-term monitoring on test plots and river gauging stations, ACED data are collected only during selected rainfall periods. There was no attempt to obtain annual results, as the accuracy of the method decreases with increasing vegetation cover and networking of rills. Consequently, ACED results can only be linked to test plots on the basis of these periods, and if rills and gullies are mapped on locations with slope, soil type and crop type comparable to one of the test plots (Figure 5.3).

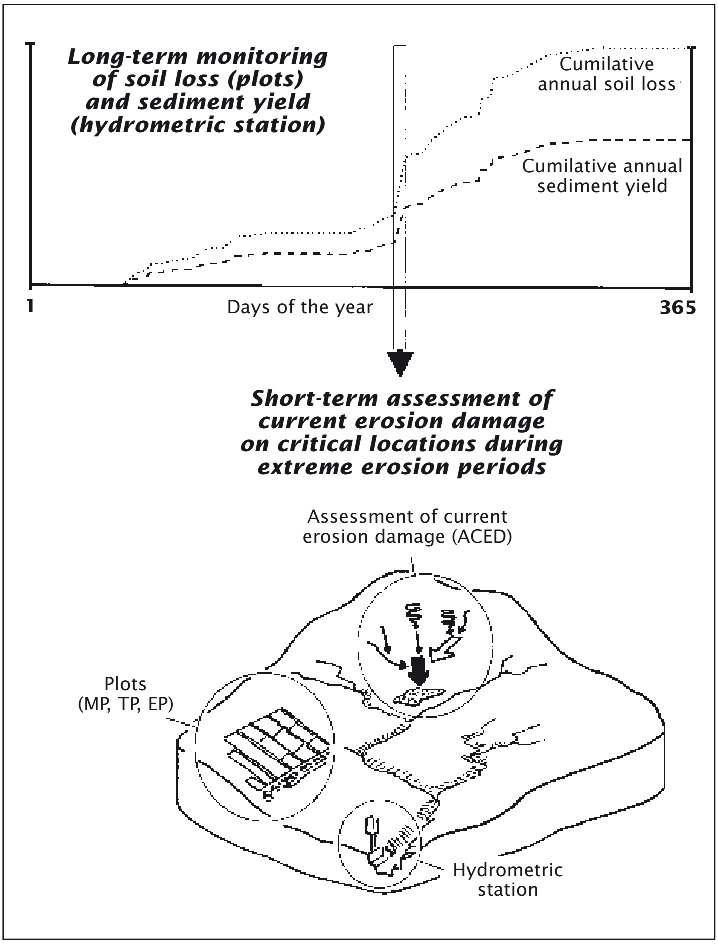


Figure 5.3 Linking rill mapping with other erosion measurements (Drawing: Karl Herweg)

A comparison of ACED with other spatial erosion measurement levels should only be made with care.

- Test plot measurements (t/ha) suggest a certain representativeness for a larger area, the „average rates and conditions“ of erosion. This is because plot conditions are controlled and influencing factors such as soil type, slope angle, and vegetation type are few in number and rather homogeneous. Thus, test plot measurements simulate an areal element, and are theoretically replicable at any location in the catchment with the same conditions.
- In contrast, rill mappings cover linear elements (even if they occupy a small area). They describe the extreme, not the average. Rills are not representative of a larger area, because their influencing factors cannot always be clearly defined or easily controlled. Therefore, rill mappings are not replicable.
- To compare mapping and plot results, it thus appears appropriate to use the unit „mm topsoil loss“ instead of t/ha. The latter unit would give the wrong impression that also rill mapping results imply area coverage, which is not always the case.
- The main sources of sediment yield measured in the river are assumed to be cropland, bare land, footpaths, embankments and the river bed itself. However, since it is not possible to estimate the extent to which each single source contributes, the entire catchment is assumed to be the area of actual damage.

The examples in Table 5.2 are an indication of entirely different dimensions of erosion. The rill mapping represents the critical location of a field with „extreme“ erosion, while the test plots represent an „average“ erosion value. The sediment yield of the respective catchment (river gauge) is included to show the amount of soil really lost from the catchment. Careful comparison of these three levels of measurement during extreme storms reveals a difference in soil movement of about one order of magnitude between each level. However, soil loss may also vary considerably. The amount of soil lost due to rill erosion, which is frequently above 100 mm, may also jump to more than 1,000 mm if the constellation of factors changes. The first three examples were measured under low vegetation cover; the last example shows a situation under higher vegetation cover. The latter reveals again that high cover does not prevent soil loss during extreme events.

From the SCRP case studies on extreme soil erosion patterns we can see that soil erosion is highly variable, both in time and space. We conclude with the hypotheses that the bulk of annual soil erosion rates is caused by a few “key” rainstorms every year, in particular at several hotspots of an erosion topo-sequence. If SWC is not able to control erosion during these periods and at these locations, it will not be able to control erosion at all! In addition, comparing the theory of soil erosion with the case studies introduced, the question should be asked: Where does reality (represented by the case studies) differ from the theory and why?

Table 5.2 Soil loss – different orders of magnitude obtained from different levels of erosion measurement

Specification	Rill mapping	Test plot
Example 1: Hunde Lafto; 24-30 May 1992; precipitation 54 mm; erosivity 44 J/m·h		
slope	46%	44%
soil texture	silt loam	sandy loam
crop type/cover	sorghum/maize, 10%	sorghum/maize, 15%
area considered	21,169 m^2	30 m^2
area of actual damage	2.9%	100%
soil loss	134 t	0.06 t
soil loss/area of actual damage	219 mm	2.0 mm
causes of damage upslope	footpath, animal track, grass, defective SWC	excluded
subsequent impact downslope	accumulation on cropland	excluded
Example 2: Maybar; 18 August 1992; precipitation 132 mm; erosivity 56 J/m·h		
slope	18%	16%
soil texture	silty clay	clay/clay loam
crop type/cover	pea, beans, teff, 5%	beans 5 - 10%
area considered	3,590 m^2	30 m^2
area of actual damage	6.0%	100%
soil loss	33.1 t	0.13 t
soil loss/area of actual damage	154 mm	4.3 mm
causes of damage upslope	defective SWC	excluded
subsequent impact downslope	accumulation on cropland	excluded
Example 3: Andit Tid; 13 Dec. 1991; precipitation 126 mm; erosivity 11 J/m·h		
slope	23%	23%
soil texture	clay loam	silt loam/silt clay loam
crop type/cover	fallow, 0%	fallow, 10%
area considered	368 m^2	30 m^2
area of actual damage	7.3%	100%
soil loss	4.6 t	0.04 t
soil loss/area of actual damage	171 mm	1.3 mm
causes of damage upslope	defective SWC	excluded
subsequent impact downslope	accumulation on cropland	excluded

Table 5.2 cont.

Example 4: Andit Tid, 16 Aug. 1991; precipitation 162 mm; erosivity 184 J/m·h		
slope	41%	39%
soil texture	silty clay	silty clay
crop type/cover	barley, 60%	barley, 50%
area considered	2.660 m^2	30 m^2
area of actual damage	43.9%	100%
soil loss	168 t	0.11 t
soil loss/area of actual damage	144 mm	3.6 mm
causes of damage upslope	defective SWC	excluded
subsequent impact downslope	accumulation on cropland	excluded

(Source: Herweg and Stillhardt, 1999)

5.3 Questions and issues for debate

From the case studies on extreme soil erosion patterns it becomes obvious that soil erosion is highly variable, both in time and space. We conclude with the statement that a few „key“ rainstorms cause the bulk of annual soil erosion rates every year, in particular at specific hotspots along an erosion topo-sequence. If SWC is not able to control erosion during these periods and at these locations, it will not be able to control erosion at all!

- In this chapter you have “experienced” how strongly soil erosion rates depend on local specificities (hot spots, e.g. a slightly diminishing gradient of a footpath, artificial concentration of runoff along a field border, etc.) and unpredictable irregularities of rainfall events. Taking this into account, what do you think is the use of generalized data such as annual values, mean soil erosion rates for the Ethiopian highlands, etc.? For whom would they be useful?
- Comparing the theory of soil erosion (e.g. high vegetation cover prevents erosion) with the case studies introduced, ask yourself: where does reality (represented by the case studies) differ from the theory and what could be the possible explanations?

6 Classification of SWC

6.1 SWC – scattered knowledge

Terms for soil and water conservation technologies and approaches are not consistently used and mean different things to different people – and even to the same people at different times (Liniger et al, 2002). In fact, no globally approved or endorsed system exists. Some given names refer to the **appearance** such as terraces, bunds ditches. Some combine the appearance with the **materials** used e.g. stonewalls, earth bunds, grass strips, some add the **slope or drainage** e.g. graded ditches or infiltration ditches. Some refer to the **land management** such as enclosure, others to the way of construction, such as "*Fanya juu*" (an assimilated Swahili term describing the way soil is 'thrown upwards' to build the bund) or to the **function and impact** e.g. cut-off drain, etc. Critchley (1999) showed that even amongst terraces there is a huge variety of names and much confusion about what 'terraces' actually are: Names include, for example, bench terrace and step terrace (metaphorical derived), forward / outward sloping terraces (describing the inclination of the bed), *Fanyu juu* terraces, Puerto Rico terraces (site-derived) and Zingg terraces (named after a person). This makes a common understanding and sharing of knowledge rather difficult (Critchley, 1999). The World Overview of Conservation Approaches and Technologies (WOCAT) was started in the 1990s as a global initiative in order to support better management of SWC knowledge (Liniger et al., 2004; Liniger and Schwilch, 2002).

6.1.1 Efficient management of existing knowledge

Every day land users and soil and water conservation specialists evaluate experience and generate know-how related to land management, improvement of soil fertility, and protection of soil resources. Most of this valuable knowledge, however, is not well documented or is not easily accessible, and comparison of different types of experience is difficult. This SWC knowledge therefore remains a local, individual resource, unavailable to others working in similar areas and seeking to accomplish similar tasks. This may be one of the reasons why soil and water degradation persists, despite many years of effort throughout the world and high investments in SWC.

6.1.2 WOCAT – making local experience available at the global level

In the past decades, there has been a heavy focus on assessing soil degradation and soil erosion, whereas there was little effort to systematically document sustainable land management practices – which is much more complicated. In fact, a wealth of SWC knowledge and information exists, and there is great demand for access to it. The challenge now is to optimize the exchange of know-how between land users and SWC specialists, such as technicians, extension workers, planners, coordinators and decision-makers. WOCAT has developed several tools to document, monitor and evaluate SWC know-how and to disseminate it around the globe in order to facilitate exchange of experience. Procedures were designed to ensure systematic recording and piecing together of local information, together with specific details about the environmental and socio-economic setting in which the information was obtained. This standardized method facilitates the transferability of knowledge to other areas of need. Collection of information involves personal contact and sharing of knowledge between land users and SWC specialists. Each type of documented experience derived directly from the field increases the knowledge base with actual rather than theoretical experience. This valuable knowledge needs to be safeguarded for the future to promote better decision-making. A set of three comprehensive questionnaires and a database system have been developed to document all relevant aspects of SWC technologies and approaches, including area coverage. These tools have been tested in many workshops worldwide, and they have been systematically optimized for five years through application in a context of international expertise. WOCAT‘s standard tools and procedures, including training workshops, help to maintain the consistency and quality of data.

At the field level, WOCAT‘s questionnaires offer SWC experts, technicians and extension workers a common framework and methodology for documenting and monitoring their own experience. One immediate benefit of filling in the questionnaires is a sound evaluation of one‘s own SWC activities. Workshops, data collection and exchange of experience provide a basis for personal contacts with other specialists for immediate exchange of experience. At the national and regional planning levels, SWC institutions, planners, coordinators and decision-makers need to obtain and maintain an overview of SWC activities. WOCAT helps to efficiently consolidate and apply relevant SWC knowledge that is available in their working areas.

6.2 The WOCAT classification of SWC technologies

The following categorization was developed in the framework of WOCAT and reflects a long and intense participatory development process.

Table 6.1: SWC classification

Management measures such as land use change, area closure, rotational grazing, etc.
▪ involve a fundamental change in land use ▪ involve no agronomic and structural measures as a priority ▪ often result in improved vegetative cover ▪ often reduce the intensity of use
Agronomic measures such as mixed cropping, contour cultivation, mulching, etc.
▪ are usually associated with annual crops ▪ are repeated routinely each season or in a rotational sequence ▪ are of short duration and not permanent ▪ do not lead to changes in slope profile ▪ are normally independent of slope
Vegetative measures such as grass strips, hedge barriers, windbreaks, etc.
▪ involve the use of perennial grasses, shrubs or trees ▪ are of long duration ▪ often lead to a change in slope profile ▪ are often zoned on the contour or at right angles to wind direction ▪ are often spaced according to slope
Structural measures such as terraces, banks, bunds, constructions, palisades, etc.
▪ often lead to a change in slope profile ▪ are of long duration or permanent ▪ are carried out primarily to control runoff, wind velocity and erosion ▪ often require substantial inputs of labor or money when first installed ▪ are often zoned on the contour / against wind direction ▪ are often spaced according to slope ▪ involve major earth movements and / or construction with wood, stone, concrete, etc.
Combinations in conditions where different measures are complementary and thus enhance each other's effectiveness.
Any combinations of the above measures are possible, e.g.: ▪ structural: terrace with ▪ vegetative: grass and trees with ▪ agronomic: ridges

(Source: WOCAT, 2003)

It is proposed that the main conservation measures are subdivided as management, agronomic, vegetative and structural. Combinations are possible. Each of these conservation categories is split up into subcategories. The main criteria are the appearance, the materials and the management involved in the technology. The proposed system works mainly on the principle of the appearance, the materials and the management involved in the technology. The function e.g. how they manage the water (control splash, control dispersed and concentrated runoff, improve infiltration or improve the fertility, their impact on the outputs etc.) should be assessed for each of the technologies separately.

M: Overall Management

Management measures (such as land use change, area closure, rotational grazing, etc.) involve a fundamental change in land use; involve no agronomic and structural measures; often result in improved vegetative cover; and often reduce the intensity of use.

- *M1: Change of land use type*: e.g. enclosure, resting, protection, change from crop to grazing land, from forest to agroforestry, from grazing land to cropland, etc.
- *M2: Change of management / intensity level*: e.g. from monocropping to rotational cropping, from continuous cropping to managed fallow, from laissez-faire to managed, from random (open access) to controlled access (grazing land forest land e.g. access to firewood), from herding to fencing, adjusting stocking rates, etc.
- *M3: Layout according to natural and human environment:* exclusion of natural waterways and hazardous areas, separation of grazing types, distribution of water points, salt-licks, livestock pens, dips (grazing land)
- *M4: Major change in timing of activities:* land preparation, planting, cutting of vegetation
- *M5: Control / change of species composition:* reduce invasive species, selective clearing, encourage desired species, controlled burning / residue burning

A: Agronomic measures / soil management

Agronomic measures (such as mixed cropping, contour cultivation, mulching) are usually associated with annual crops; are repeated routinely each season or in a rotational sequence; are of short duration and not permanent; do not lead to changes in slope profile; are normally not zoned; and are normally independent of slope.

- *A1: Vegetation / soil cover*: better soil cover by vegetation, early planting, relay cropping, mixed cropping / intercropping, contour planting / strip cropping, cover cropping, retaining more vegetation cover, mulching, temporary trash lines, others
- *A2: Organic matter / soil fertility*: legume inter-planting, green manure, applying manure / compost / residues (organic fertilizers), applying mineral fertilizers (inorganic fertilizers), applying soil conditioners (e.g. use of lime or gypsum), rotations / fallows (associated with M), others

- *A3: Soil surface treatment*: conservation tillage (zero tillage, minimum tillage and other tillage with reduced disturbance of the top soil), contour tillage, contour ridging (crop and grazing land), done annually or in rotational sequence,
- *A4: Subsurface treatment*: breaking compacted subsoil (hard pans): deep ripping, "subsoiling", deep tillage / double digging, others

V: Vegetative measures

Vegetative measures (such as grass strips, hedge barriers, windbreaks, etc.) involve the use of perennial grasses, shrubs or trees; are of long duration; often lead to a change in slope profile; are often zoned on the contour or at right angles to wind direction and are often spaced according to slope:

- *V1: Tree and shrub cover*: dispersed (in annual crops or grazing land), aligned (in annual crops or grazing land): e.g. live fences, hedges, barrier hedgerows, alley cropping), in blocks (e.g. woodlots)
- *V2: Grasses and perennial herbaceous plants*: dispersed, aligned (grass strips)

S: Structural measures

Structural measures (such as terraces, banks, bunds, constructions, palisades, etc.) often lead to a change in slope profile; are of long duration or permanent; are carried out primarily to control runoff, wind velocity and erosion; often require substantial inputs of labor or money when first installed; are often zoned on the contour / against wind direction; are often spaced according to slope; and involve major earth movements and / or construction with wood, stone, concrete, etc.:

- *S1: bench terraces* (<6%) (if combined with S3, S4 and S5 indicate the combination): level (incl. rice paddies), forward sloping / outward sloping, backward sloping / back-sloping / reverse
- *S2: forward sloping terraces* (>6%): (if combined with S3, S4 and S5 indicate the combination)
- *S3: bunds / banks* (if combined with terrace, combination is indicated): level (tied, non-tied), graded (tied, non-tied), semi-circular, v-shaped, trapezoidal, others.
- *S4: graded ditches, waterways* (to drain and convey water): cut-off drains, waterways
- *S5: level ditches, pits*: infiltration, retention, sediment / sand traps
- *S6: dams / pans*: store excessive water
- *S7: reshaping surface* (reducing slope) / *top soil retention* (e.g. in mining storing top soil and re-spreading
- *S8: walls, barriers, palisades* (constructed from wood, stone concrete, others, not combined with earth)
- *S9: others*

These categories allow a better overview over a number of more or less different single SWC technologies (or measures). However, such classification is to a certain extent deliberate, because in practice, these components always occur in combination. For example, a terrace (structural) involves a ditch and a small dam that is stabilized by grasses and trees (vegetative), and the area of cereal production can only be plowed along the contour (agronomic). The most effective erosion control component is certainly a dense plant cover, and thus, agronomic and vegetative SWC are given highest priority in soil protection. At the same time, these measures mostly involve a direct economic return in the form of biomass production. However, after a dry season of several months, there is hardly any vegetative cover to protect the soils from intensive rains. Therefore, a well-designed system of structural SWC measures provides protective function until the plant cover takes over. Structural measures gain importance also, when runoff from roads, settlements, etc, enters and damages cropland. In arid areas, plant cover might always be low so that soil protection always relies on structural measures. Optimal conservation effects can be achieved if all components are integrated into one farming and protection system.

6.3 SWC – principles of functioning

Attempts to systematize SWC terminology and the enormous variety of technologies have produced an unnumbered amount of SWC handbooks and guidelines. The systematic description of a technology, however, has shown another side-effect: an SWC expert without much field experience – i.e. at the beginning of his/her career – will not question the design and technical details of a technology and will try to implement it as it is described in the reference book. A predetermined mind, however, can seriously hamper participatory approaches and prevent experts from considering farmers' opinions, indigenous knowledge and thus site-specific experience, which in the past has led to severe problems of acceptance and adaptation of SWC.

Therefore, before focusing too early on one specific technology, a definite construction material, a fixed spacing, one type of plant, etc. it is recommendable to start a discussion with the user of the land under consideration open minded. The "conservationists' mind" could be kept relatively open, for example, by focusing on the "principles of functioning" that are required to respond to a set of challenges. For example, when we see a long slope showing negative effects due to uncontrolled surface drainage, the first thing which comes to our mind is often "terracing". Before getting too much exited of this "solution", we should first think whether terracing was the only way to diminish runoff velocity, or if there would be other alternatives, such as vegetation, ditches, trash lines, etc. Another example is given by the term "soil bund". Since "soil" is a precious resource, why waste it by constructing bunds instead of using stones, residues or other materials that are locally available? Being equipped with the principles of functioning (Figures 6.1 to 6.4) and a pool of SWC technologies, a conservation expert should be in a good position to be a competent partner for assisting land users in practicing a more sustainable land management. To describe these principles, it was found useful to regroup the above-mentioned SWC categories into four groups with similar functions: (1) vegetative and agronomic SWC (2) structural SWC in humid areas, (3) structural water conservation in arid areas, and (4) wind erosion control.

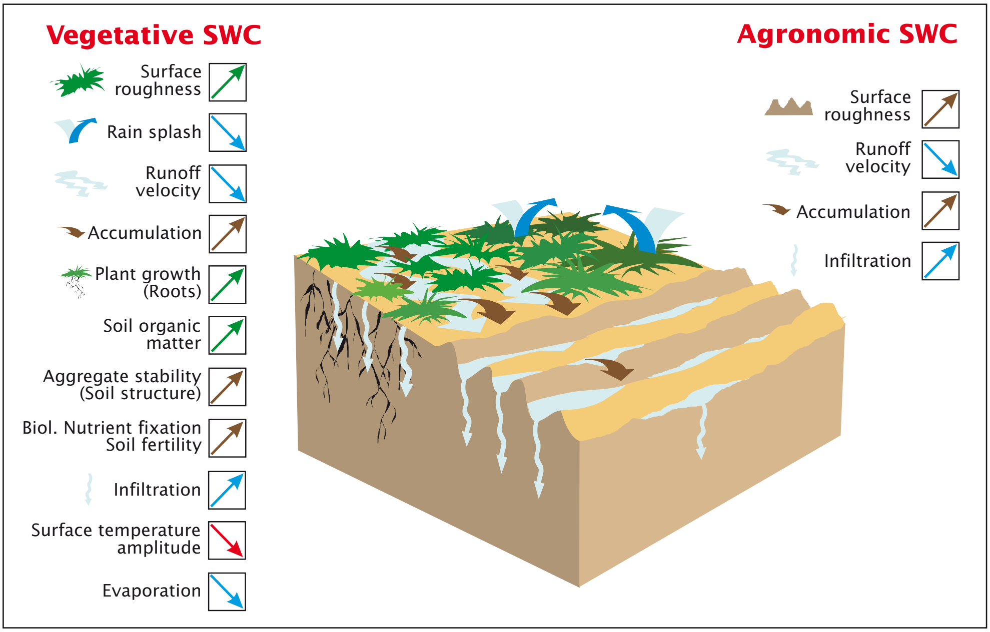


Figure 6.1: Principles of functioning – vegetative / agronomic SWC

Vegetative and agronomic measures create effects both above and below the soil surface. Plants, plant residues, but also stones, coarse clods (soil aggregates), ripples etc. form an increased surface roughness that in turn enforces a reduction of runoff velocity, accumulation of eroded particles, and provide an extended time of infiltration. In addition, plants and mulch reduce the effect of rain splash, decreasing the amplitude of the surface temperature and thus help reduce evaporation losses. Plants also help increase infiltration in many ways: (1) directly through their roots, and (2) indirectly by increasing organic matter and thus improving aggregate stability and the soil structure. Selected plant types improve soil fertility by fixing macronutrients such as Nitrogen. Improved soil fertility, in turn, serves again for better plant growth. The soil-plant-system may thus stabilize itself ensuring both production and protection functions (Drawing: Karl Herweg).

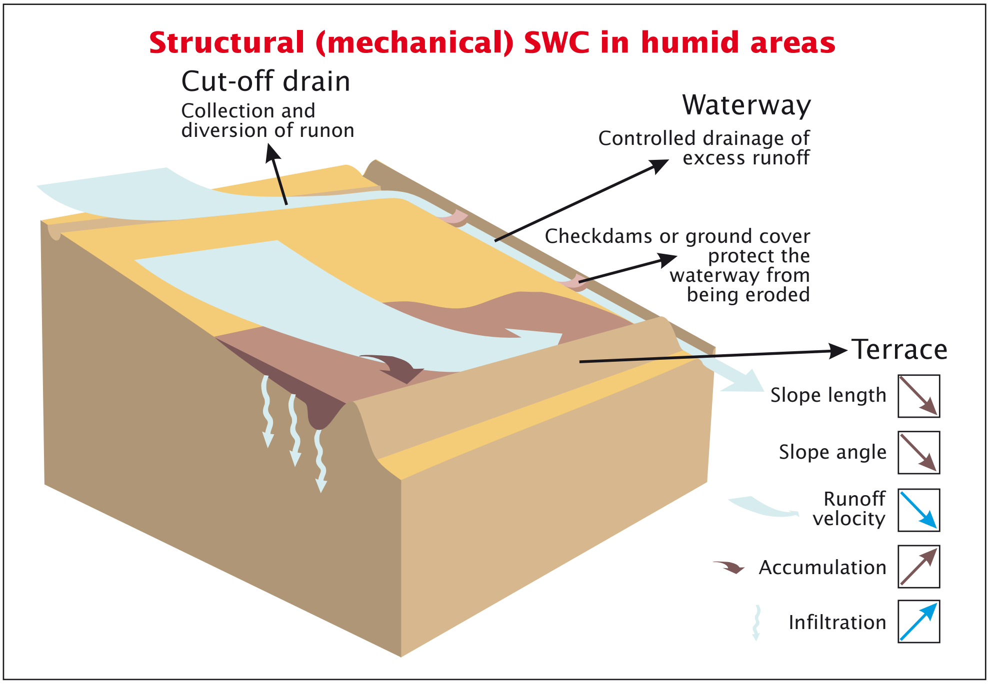


Figure 6.2: Principles of functioning – structural SWC in humid areas

Catchments in humid areas often face a general problem of surplus overland flow. The first task may therefore be to protect the uncovered cultivated parts from external sources of water – the so-called runon. Particularly at the beginning of a rainy season, when there is less protective vegetation available, it is mostly drainage channels or ditches, so-called cut-off drains that serve as a runon control. On cultivated fields, structural measures such as ditches, terraces, bunds etc. help interrupt (decrease) slope length. With time, also the slope angle will be diminished when structures gradually develop into terraces. To safely drain excess water, these structures are graded. Both reduced slope length and slope angle help slow down runoff velocity, encourage accumulation of eroded particles, and extending the time of infiltration. Vegetative strips, hedgerows, etc. can achieve the same effects, provided that before there was sufficient water available and controlled grazing to maintain a certain plant cover. Cut-off drains and terrace channels collect a lot of runoff that needs to be safely drained out of the cropping area and out of the catchment. Such waterways can be natural or artificial drainage lines that should be protected from erosion themselves, for example by a dense ground cover (grass, stones) or wooden / stone checkdams. Waterway – or gully – protection measures focus also on reducing runoff velocity and enforcing accumulation of eroded material (Drawing: Karl Herweg).

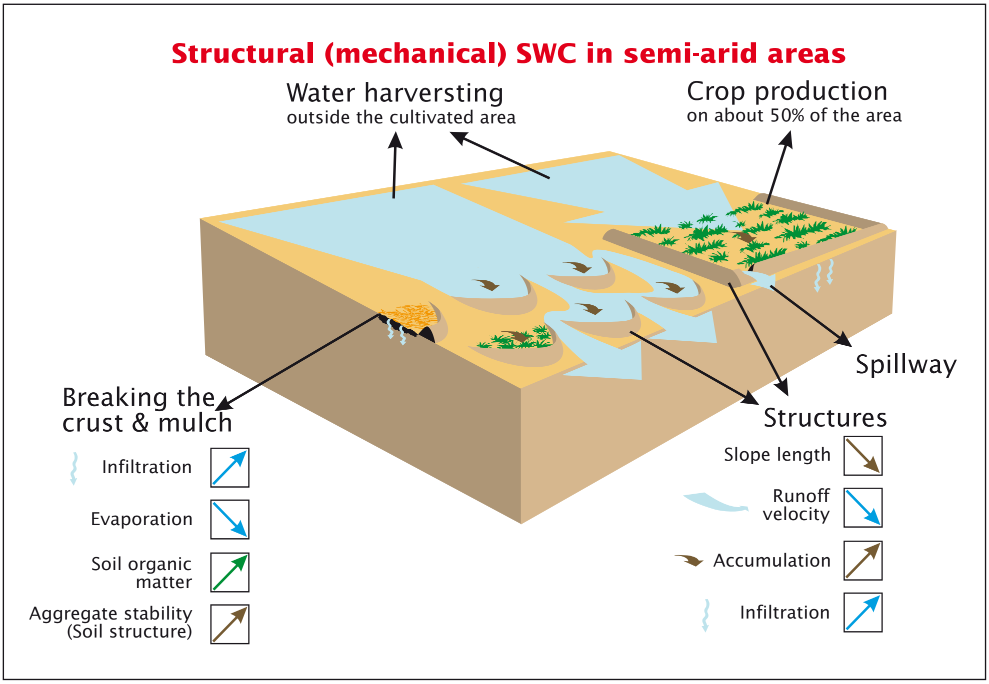


Figure 6.3: Principles of functioning – structural SWC in semi-arid areas

In arid areas rainwater is commonly insufficient for production. A first measure is, therefore, to split the area in different functions. Only a certain part of a slope – e.g. 50% - will be used as cropping area, while the remaining part serves as external "catchment" for collecting / harvesting rain water to be drained onto the cropping area. The latter needs both runoff and infiltration management. Soil crusts must often be broken to enable infiltration. Mulching can minimize evaporation losses. With time, soil structure (aggregate stability) and organic matter content can be gradually improved. At the same time, structures of different shapes – half moon and rectangular forms – will keep overland flow as long as possible in the cropping area. Excess water will be drained around or through these structures (via spillways) onto the next cropping area and structure downslope. In this manner, slope length is reduced to minimize erosion risk during heavy rainfall events. Consequently, runoff velocity is reduced, accumulation of eroded particles is enhanced, and infiltration increased (Drawing: Karl Herweg).

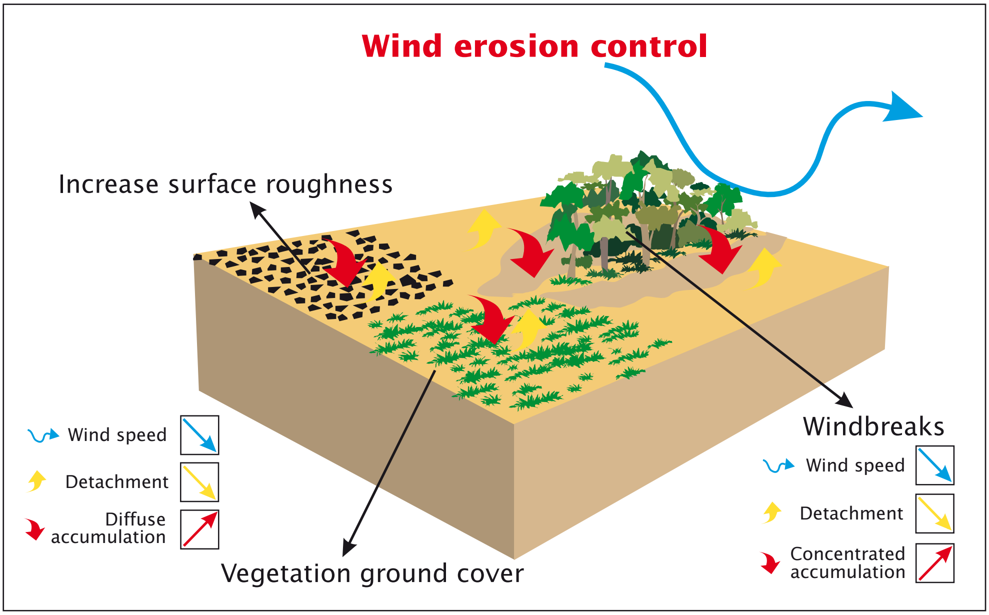


Figure 6.4: Principles of functioning – wind erosion control
Controlling wind erosion can be separated into prevention of detachment and re-accumulation of already eroded materials. In both cases, wind speed must be diminished. It needs to be kept in mind that eroded soil particles blown over a surface with high-speed work like sand paper – they destroy the surface by detaching further material. Increased surface roughness, either by plants or large soil aggregates and clods reduce wind speed near the soil surface, eroded particles accumulate in diffuse accumulations, and detachment is largely decreased. Barriers, so-called windbreaks consisting of higher trees, bushes and ground cover, reduce wind speed in the first couple of meters above ground. Typically, accumulations of eroded material concentrate immediately before and after the barrier (Drawing: Karl Herweg).

6.4 Questions and issues for debate

- Categories of SWC are helpful to get an overview over a confusing number and terms of SWC technologies. But they cannot represent reality with all its facets, which consists of constant change, dynamic behavior and changes, and continuous transitions between categories rather than clear-cut distinctions of classes. For example, large parts of the Ethiopian highlands can be considered sub-humid, which would basically require consequent drainage of excess runoff to prevent soil erosion. However, there are always single years or rainy seasons that are rather dry (drought). Thus, the standard SWC scheme that works perfectly in most years can create a problem of water retention in exceptional years or seasons. How would you handle this challenge?
- How does the WOCAT scheme correspond to land use planning and land evaluation classifications?

7 Development of SWC Technologies

7.1 Indigenous Ethiopian SWC measures

Plowing systems, including furrowing to divert water

Definition, specifications and purpose

In Ethiopia, there are numerous different traditional plowing systems, which are characterized by a high adaptation to the local ecological conditions (soil, rainfall, altitude, etc.) as well as to social circumstances (fasting times, religious taboos). In the beginning of and during the rainy season farmers must always plow along the contour. For some management purposes, it might be necessary to plow up and down, but this practice must strictly be limited to the dry season. The main purpose of such systems is in the first place to increase the yield by optimal preparation of the soil for the crops, with the opportunity of SWC as a desirable side effect.

Table 7.1: An example of a sophisticated, traditional land management system from the Eritrean Highlands

Type of plowing	Months	Direction of plowing	Function and specific descriptions
Sito	June and July	Contour (wide furrow plowing)	Preparation of the soil for the coming summer rains, mainly intended for water conservation (increased infiltration).
Aimi	October and November	Up and down slope plowing (no rain during this time)	To break existing furrows and to prepare the land for the next practice. Narrow plowing is also used to minimize evaporation
Teslas	December and January	Plowing along the slope (no rain during this time)	To break existing furrows and to prepare the land for the next practice. Narrow plowing is also used to minimize evaporation
Mimgab	March	Contour plowing	Increasing the soil surface roughness. Preparation of the soil for the first rainfalls.
Mgunbat	May	Contour plowing, wide furrow	Increasing infiltration through contour furrows. The land is now ready to take up the spring rainfall.
Mirwah	June	Turn up side down (if there are grasses or weeds)	Weed protection
Sowing	June/ July	Contour plowing (narrow furrow)	Narrow plowing during sowing time (high erosion risk)

(Source: Gurtner & Stillhardt, 2006, in prep).

Crop rotation, fallowing (temporary area enclosure) and rotational grazing

Definition, specifications and purpose

Cultivation of different crops in recurring succession on the same land during e.g. three consecutive years followed by at least one year of fallow (leaving the field without agricultural activity, except grazing). As an example: in Afdeyu (Eritrea) the four-year-crop rotation cycle includes the following periods:

- *Tsigie* is the first season of crop cultivation following one year of fallow. During this period farmers practice different types of indigenous plowing practices as presented above, in order to break hard pans, incorporate plant residues, improve soil aeration and water infiltration and to promote seed germination. During *Tsigie* farmers want to make maximum use of the nutrient status of their land. Higher yields and financial benefits can be expected, which animates farmers to invest more during this period. Barley is the common crop sown during *Tsigie*, whereas plots, which are near to the village and thus easily accessible are sown with potato, beans or maize. All these crops need a comparatively high fertility status.
- The second crop rotation period is called *keriem*, that means “crop residues after harvest”. Remaining straw from the former harvest is decomposed in situ to increase the content in organic matter. Land management is reduced to two tillage practices. Commonly mixed cropping of wheat and barley is practiced during *keriem*. Some farmers also associate soya bean and maize.
- *Salsien* is the third and last cropping season before fallowing. Even though there is a decrease in production due to declining fertility, there are almost no soil management and SWC activities during salsien. Soil fertility management is minimized, and normally farmers don’t want to waste capital, energy and time in this last cropping period before fallow.

After three consecutive years of cultivation, the land is left fallow for one year. During this period, land is temporarily enclosed and no land management practices take place. Grazing, cut and carry of grasses, and even collection of wood is prohibited. The land is re-opened for grazing towards the end of the enclosure (end of May).

7.2 Proper planning of SWC

The proper planning of soil and water conservation technologies and its implementation depends on measurements, observations, estimations and perceptions made by different stakeholders like practitioners, technicians, politicians, scientists, development agents etc. Before starting a discussion about appropriate measures, it is often important to check whether all stakeholders involved rely on the same understanding of the concepts and terms used. The term “SWC” implies improved management of the two resources “soil” and “water”, in order to maintain (support, increase) in a medium- to long-term perspective the production capacity of these resources, often measured in terms of crop yield.

Planning and implementing a technology is always a reaction to one ore more (degradation) problems (cf. Chapter 2), which are identified through observations that are largely determined by the specific perception and knowledge of the observer. If a specific SWC technology is directly selected based on the problems perceived, the choice of potential SWC options is limited too early and unnecessarily. It is rather recommended to get clarity first on what principles of functioning (cf. Chapter 6) are required to adequately respond to the problems perceived. In this context it is important to note that implementation of SWC measures based on agro-technical and scientific knowledge alone is likely to lead to unsatisfactory results. The selection of appropriate measures must consider all three dimensions of sustainability (social, economic and ecological). A selection of important factors influencing the decision for a certain measure or a set of measures is given below:

- type of degradation, e.g. by water, by wind, chemical or physical deterioration (for details see list below);
- agro-climatic zonation (see also Chapter 3) and corresponding limitations, such as humidity, aridity, altitude;
- landform, e.g. plateau, ridge, valley floor, slope length and steepness, ...;
- soil characteristics like depth, texture, structure, fertility and organic matter, surface stoniness, drainage, soil suitability for different crops, erodibility, ... ;
- what is locally considered as staple food, main crops grown, cash crops, etc.;
- land ownership and land rights;
- personal preferences of the land user concerned;
- expected short and medium term economic benefits and farmers planning horizon;
- costs for labor, equipment, agricultural material, availability and costs of wage labor;
- expected effect of the measure e.g. control of raindrop splash, control of dispersed runoff, control of concentrated runoff (retain / trap, impede / retard, drain / divert), reduction of slope angle, reduction of slope length, increase of surface roughness, improvement of soil structure, increase of infiltration, increase / maintain of water stored in soil, water harvesting, water spreading, increase in organic matter, increase in soil fertility, sediment harvesting, improvement of ground cover, reduction in wind speed, etc.;
- knowledge and professional background of implementer, project designer, program, project goals;
- incentives (in cash and kind) and extensional support.

The term “soil and water conservation” reflects a dual option, and it depends on the humidity of an area and the stakeholders’ goals which option is more important.

- In sub-humid areas, the main focus lies normally on soil conservation with the opportunity to conserve moisture during times of low rainfall.
- In semi-arid areas, emphasis is given to water conservation with the option to prevent soil erosion during heavy rainstorms.
- In areas with both long rainy seasons with extended dry spells, the art of SWC is to combine both effects.

It is obvious that the farming practices and technologies described in what follows have different functions, the most important of which is food production. In this document, however, we will focus on the erosion control function of these measures.

7.3 Structural (mechanical) soil and water conservation

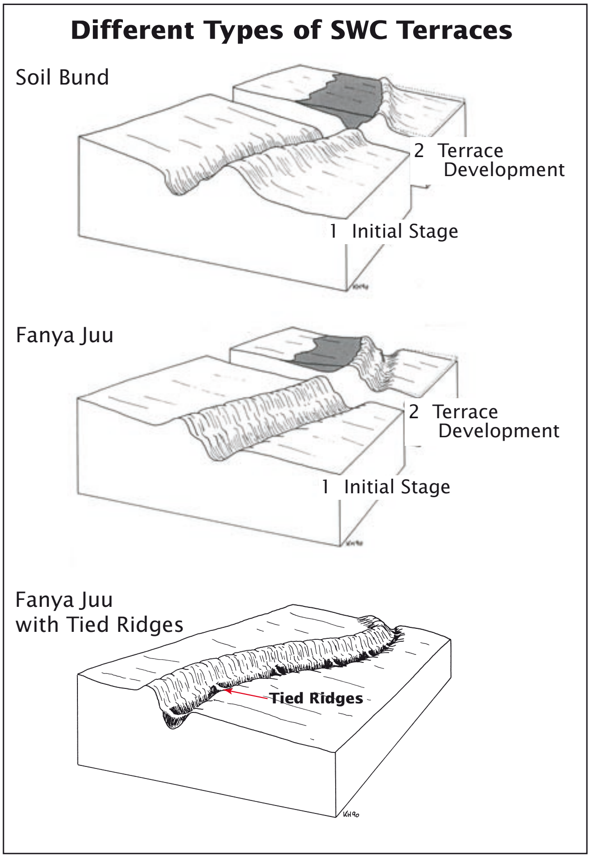


Figure 7.1: Some examples of terraces and terrace development (Drawing: Karl Herweg)

- **Diversion ditch / cut-off drain:** a graded channel with a supportive ridge or bank on the lower side. It is constructed across a slope and designed to intercept surface runoff and convey it safely to an outlet or waterway.
- **Waterways:** are needed to conduct runoff safely from hill slopes to valley bottoms where it can join a stream or river.
- **Retention / infiltration ditch:** large ditches designed to catch and retain all incoming runoff and hold it until it infiltrates into the ground.
- **Pit:** planting holes (for example those used widely in the West African Sahel).
- **Sediment / sand trap:** device (either an above ground barrier or a dam wall) built specifically to trap sand or sediments moving in the wind or in water flow.
- **Dam / pan:** blockage of watercourse or excavation at a low spot of land to collect water for various purposes.
- **Terrace:** involve a more or less permanent change in slope profile.
- **Level bund / bank terrace:** an embankment along the contour made of soil and / or stones with a basin at its upper or lower side. They often develop into forward sloping terraces.
- **Graded bund:** as level bund, but slightly graded (with 1-4%) towards a waterway or river.
- **Wall, barrier:** physical obstacles to movement of soil or sand, e.g. artificial windbreaks (palisades), can be made from various materials.
- **Reshaping surface:** smoothening of land surface, e.g. of mining sites, gullies (cutting edges), etc.

Structural (mechanical) soil conservation in sub-humid areas

From the erosion point of view, the most urgent problem in sub-humid areas is to control excess runoff. In response to that, common **drainage systems** involve various components. A cut-off drain along the upper field border protects the cropland from runon sources of the upslope areas. On the cropping area itself terrace channels, subsurface drains, waterways and storm water drains lead the overland flow safely into the next river. Since these drainage ditches have to deal with highest water concentrations, they can easily be eroded themselves. They may need to be protected by checkdams, a dense grass cover (grassed waterways) or even a sealed surface (stone covered waterways).

The steeper the slope, the more needs the drainage system to be supported by **terraces** in order to reduce slope length and slope gradient. A terrace usually contains a drainage ditch and a dam of low height. The most common types are reverse or inward sloping terraces, outward sloping terraces, contour (level) terraces and graded terraces (faster drainage). Terraces can be constructed in one go, or they grow slowly using sheet erosion processes as a “constructor” (progressively developing terrace). In the year of initiation, only small ditches and dams are constructed. With time, eroded soil accumulates above the dams and creates small steps. If the dams are made higher at regular intervals, a terrace develops within a couple of years. The construction material can be stones, soil or other materials. Differences can occur in the position of the dam and the spacing of terraces (depending on slope). Bunds (soil bund, stone bund) have the channel uphill and the dam downhill, while *Fanya Juu* have a dam uphill and channel downhill. **Stop-wash lines** serve similar purposes as terraces. They are built from soil, stone straw or other organic material (trash lines). They are mostly temporary structures, which collect fertile sediment, which can be re-distributed over the field.

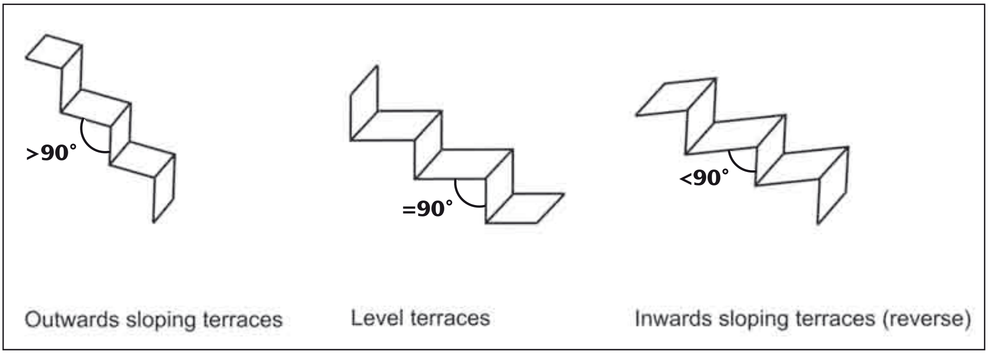


Figure 7.2: Outwards sloping terraces, level terraces and reverse terraces (Drawing: Brigitta Stillhardt)

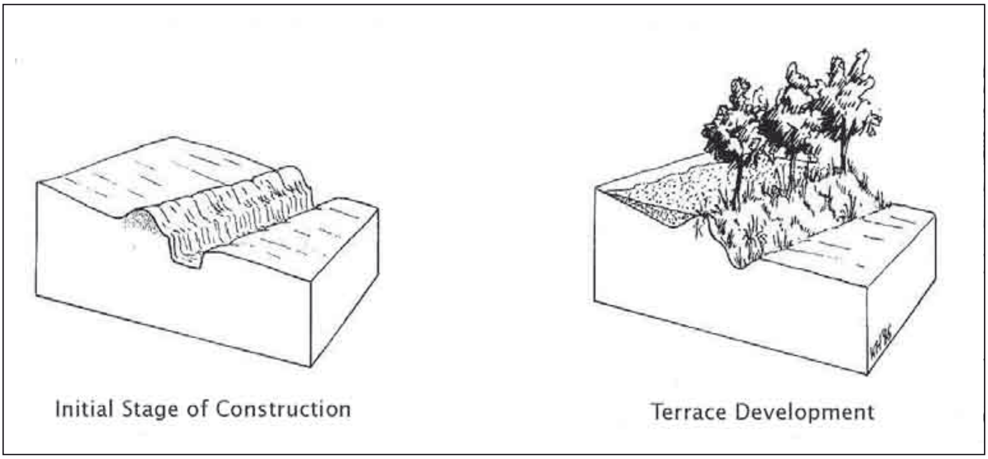


Figure 7.3: Design and development of a Fanya Juu terrace (Drawing: Karl Herweg)

Structural (mechanical) soil conservation in arid and semi arid areas

Water and moisture conservation is the primary purpose of SWC practices in arid and semi-arid areas. Long dry seasons limit the use of vegetative measures, and the few but intensive rainstorms require structural components, such as ditches and terraces or terrace-like structures. In contrast to sub-humid areas, the most important aspect in drier areas is water retention and water storage on cropland. In addition, the same technologies help reduce soil erosion during periods of heavy rainfall. Due to general water shortage, only part of the available area can be used for crop production. Thus, the upper part (catchment area, within-field catchment) is used to collect rainwater and to safety lead all available runoff onto the lower – cropland – part (water harvesting) through drainage systems (rainfall multipliers, diversion channels, floodwater spreading). On sloping lands, contour terraces reduce runoff velocity and extend the time span for water to infiltrate into the soil system. In addition, spillways (sluices) in the terraces, waterways protected by stone checkdams, and tied ridges or listing provides safe drainage during extreme storms. On flat slopes, rectangular or semi-circular structures (half-moon structures, demi-lunes) and smaller micro basins fulfill the same purpose as terraces on sloping land.

Photo 7.1: Integrated soil and water conservation structures in Hunde Lafto, Ethiopia. Question: What structural (mechanical), management and vegetative measures can you identify on this picture? (Photo: Karl Herweg 1995)

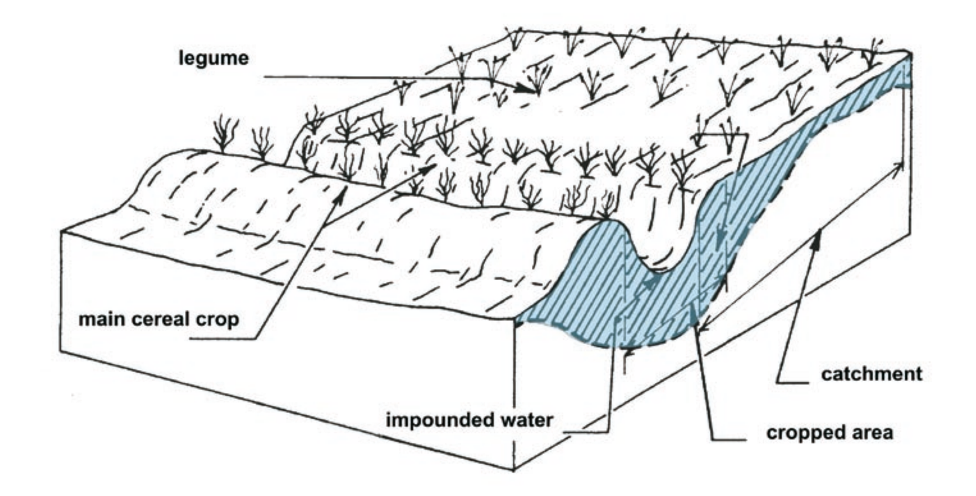


Figure 7.4: Principle of moisture conservation in semi arid environments (Source: Pacey and Cullis, 1986)

Description of selected structural SWC technologies)

Terraces

There are different types of terraces and terrace development, but common to most of these structures are the following potentials and limitations:

Potentials, benefits
- Converts marginal land (hillsides) into cultivable, arable land; reduces land scarcity
- Efficient protection from erosion, good conservation of soil and applied fertilizers
- Conserves both soil and water
- Increases soil fertility and crop yield in particular near the lower end of the terrace (siltation of eroded topsoil)
- Enables to plant many types of crops and reduces the risk of harvest failure

Limitations, weaknesses
- Height of terrace can cause instability if not maintained
- Narrow spacing can be an obstacle for turning of oxen plow
- Structures occupy part of the area (loss of arable land)
- Frequent maintenance is needed to avoid these problems and to counter siltation
- Drainage of excess water is can be problematic when the gradient is low or diminishing; sometimes water overflows
- Water logging especially on clay soils
- Land management becomes more complex

Photo 7.2: Two examples of stone terraces in a semi-arid environment (Afdeyu, Eritrea; Photos: Mats Gurtner, 2004)

Soil (earth) and combined stone / earth bunds

Definition, specifications and purpose

Stone bunds are wide spread and well known in the area and a lot of varieties can be found in Eastern Africa (e.g. Fanya chini, Swahilii for “throw downhill”), ranging from semi-permanent simple structures to intensively maintained terrace development raisers to limit the risk of overflowing. Stone bunds are constructed where suitable stones are available on or near the field. They are preferred in subhumid environments because the drainage of excess water is better than on soil bunds. A stone layer often makes the foundation, while a combination of stones and soil is used during further development. Pure soil bunds are susceptible to heavy rainfalls and easily eroded by water and wind.

There are basically two types, which may have an identical appearance but a completely different purpose and origin / genesis:

- Soil bunds covered by grass are often developing over years on the small, unplowed strip between two fields and not following the contour lines. Originally, the main purpose was not SWC but demarcation of the boundary between two properties, although the conservation effect is well known. Some farmers even enhance these permanent bunds by adding stones on top.
- The purpose of combined stone and soil bunds within a field / property is to increase proportion of arable land through leveling of steep land; reduction runoff and stop erosion. Aligned along the contour, bunds can be both permanent and temporal structures. Terrace risers are often not stabilized with stones; particularly the lower parts can be undercut through erosion and stones fall off, or they are removed to increase the arable area. Maintenance of terraces depends on several factors, the most important ones being integration into the management system, availability of stones, accessibility of the field, removal of stones for cultivation.

Potentials, benefits

- If well maintained, stone terraces are stable and durable
- Excess water can pass through the stone terraces
- Bunds minimize the velocity of runon
- Labor demand is lower than the one of Fanya Juu
- Can easily be integrated in other land management activities
- Grass, sown at the top of the bunds helps stabilizing the structure and can be used as fodder (cut and carry)
- Loss of land is comparably low

Limitations, weaknesses

- An alignment that does not follow the contour but the traditional field boundaries can lead to lateral flow, concentration of runoff and overflowing at the lowest point
- On clay soils terraces can create water logging
- Open animal grazing easily enforces development of cattle pathways, a major source of soil erosion
- No active runoff control
- Removal of stone by the farmers for construction work
- Spillways can create problems for the subsequent fields.
- Overflow with high runoff
- Low durability of newly implemented soil bunds; needs frequent maintenance

Fanya Juu terraces

The design and development of a Fanya Juu can be studied in Figure 7.1 and Figure 7.3. Its purpose is to protect the high potential land, and to conserve soil and water. *Fanya Juu* (Swaheli for "throw uphill") is an embankment along the contour made of soil and / or stones, with a channel at its lower side where overflowing runoff is collected. The *Fanya Juu* reduces the velocity of overland flow and consequently soil erosion. *Fanya Juu* is well known in Kenya and introduced for test purposes in the 1980s in Ethiopia.

Potentials, benefits

- If maintained highly effective soil and water conservation (See also example 2 in Chapter 4)

Limitations, weaknesses

- Needs high labor input, therefore often applied only on severely eroded fields
- In steeper areas with high runoff there is a risk of overtopping
- Structure occupies a lot of space on steep slopes

Temporal "moving" bunds

Definition, specifications and purpose
Some bunds are temporally constructed for a specific purpose, such as to increase topsoil depth, or to divert surface runoff. After this purpose is fulfilled, the fertile earth of these bunds are distributed and incorporated by plowing to fertilize the fields. The stones are dislocated within the field and incorporated into another temporal structure. In slope depression, such new bunds are often established directly below the former one. Where possible, the bunds are made of stones, since soil is too precious (fertile). During plowing soil is moved towards the stone bund. "Moving" bunds are often found in fertile "Ghedena" land (Atakilte et al., 2001).

Potentials, benefits
- Fertile soil material is used for soil improvement
- Low continuous labor demand

Limitations, weaknesses
- Potentially less effective than permanent structures in terms of conservation

Hillside terracing

Definition, specifications and purpose
Hillside terracing is practiced in mountainous areas with slopes >30% to protect reforestation areas. The effect of hillside terraces is the same as for stone bunds but hillside terracing is combined with cut and carry. The spacing of the terraces in afforestation areas is narrower than on cropland.

Potentials, benefits
- Protection against wind and water erosion
- Moisture and soil conservation

Limitations, weaknesses
- Susceptible under uncontrolled grazing
- Some types of grass sown under the trees, (e.g. elephant grass) are not drought resistant, and need irrigation

Tied ridges

Definition, specifications and purpose

Tied ridges are exclusively constructed in combination with earth bunds or stone / earth bunds. They consist of excavated ditches or pockets of a few meters length on the upper side of a bund (See Photo 7.3). The ditches are "tied" (separated) by small "ridges" of undisturbed soil. The width of the ditch is up to 1m, whereas the depth during the initial stage varies between 30 and 50 cm. The small tied ridges are lower towards the centre so that excess water can overflow from one ditch (pocket) to the next. The main purpose of the tied ridges is to increase infiltration and to conserve the water in situ.

Potentials, benefits

- High efficiency in water conservation
- Fertile soil is accumulated in the ditches and can be re-used
- Remarkable yields in dry years
- Prevents lateral erosion of water and destruction of structures
- Enhance dense grass cover (also in the ditches)

Limitations, weaknesses

- Occupy a large proportion of arable land up to 2 – 2.5 m
- If not properly aligned along the contour, water concentrates at the lowest point, accumulates, and may break bunds
- Water logging may occur in the rainy season
- Requires high labor input, not only during the initial stage but also during every maintenance (fast siltation of ditches)

Photo 7.3: Silted up tied ridges after water is infiltrated. The picture was taken after a first rainfall and the effect of tied ridges is visible around the basins where grass cover is denser than in other areas of the field. (Photo: Brigitta Stillhardt, 2004)

Microbasins and half-moon structures

Definition, specifications and purpose

Micro-basins, half moons and other micro catchment technologies are mainly used in dry areas for water conservation. In semi arid and sub humid areas micro basins are mainly found in forest areas and on steep slopes or very shallow soils. Such structures are often constructed manually, using earth and stones, outlined in lines of staggered formation. Runoff water is collected within the basin from the area above and impounded in the structure. Excess water is discharged around the tips and is intercepted by the next row of micro basins. Normally the semi-circles are of about 4-12 m in radius with a height of about 30 cm and a base width of about 80 cm. The percentage of enclosed cultivated area depends on the rainfall regime of the area.

Potentials, benefits

- Rainfed plant growing is possible in areas with less than 300 mm of annual rainfall
- Top-soil sediments are also trapped in the structures gradually improving soil fertility

Limitations, weaknesses

- Establishment of half-moons is labor intensive
- Construction requires know-how and experience

Photo 7.4: Water harvesting in a micro catchment in Niger– two types of half moons are shown, one made of soil, the other of soil and of stones. (Photos: Michel Evequoz).

Gully / piping reclamation

Definition, specifications and purpose

The purpose of reclamation is both to protect and repair terraces and waterways that are either threatened or already affected by pipe erosion. This is important because (further) terrace collapse and gully erosion would enlarge the already eroded cropland and lead to more subsequent downstream erosion. Reclamation of gullies and piping always requires a package of structural conservation measures, including check dams, gabions, earth filling and diversion of runon. Some farmers tried to solve the problem of "piping" by simply filling the sacked part / the pipe with stones, earth and other material. This method often fails since subsurface erosion tends to continue despite the filling. If this method is applied it definitely should be supported by additional measures such as protecting bunds upstream. The best time of gully / pipe reclamation is during the dry season, or when the affected area is left fallow.

Potentials, benefits

- Recover a lost cropping area within a short time
- If well designed, the structure is almost free of maintenance activities, apart from occasional monitoring
- Prevents expansion of the damaged area
- Facilitates land management on the terrace considerably (e.g. plowing)
- Conserves water and accumulates soil
- Prevents concentrated runoff and downstream damages
- Water is diverted laterally and thus waterlogging is avoided

Limitations, weaknesses

- Requires a high initial input for establishment
- High labor inputs
- Requires expert knowledge and / or some experience to construct a check dam with good foundation and functioning spill ways
- Availability of large stones

Water harvesting, diversion and drainage systems: ditches, bunds and spillways

Most cropland is characterized by an uneven distribution of surface water flow, which usually concentrates in slope depressions, in furrows, in the lower part of a field (on slopes) and at the bottom of concave landforms. Farmers try to retain runon on the upper part of an inclined field or – in case of a valley – divert it to the lateral sloppy areas (areas naturally receive less water due to their topographic position) to achieve an even distribution of available rainwater on their fields.

Definition, specifications and purpose

Through local innovation and experimentation farmers developed sophisticated systems to regulate water availability and drainage (runon and runoff). These systems mainly consist of:

- Short graded stone and earth bunds (diversion bunds), to divert water from roadside / footpath / waterway into cropland (water harvesting structure), combined with inlets
- Graded stone and earth bunds (diversion bunds); straight or bent (form of halfmoon); to distribute / divert water within field and at the same time to minimize gully development and piping in weak zones
- Diversion ditches, combined with bunds or as single measure
- Deep plowed furrows
- Spillways in existing stone and earth bunds along the contour that help draining excess water
- Stone diversion bunds: temporal structural SWC constructed by making ridges of stones which are protruding from the main bund or terrace to convey water to the middle of a field and further divert it to sub plots
- Temporal stone / earth bunds with convex design, along the natural water course to protect hot spots, such as broken terraces and gully heads from further erosion
- Diversion ditches (also cut-off drains, mainly used in flat areas to drain (not divert) water out of areas with waterlogging
- Stone / earth diversion bunds within fields: semi-permanent structures dividing the runon in two flow-directions
- Roadside water harvesting structures: small, seasonal structures to collect roadside runoff
- Spillways: semi permanent or seasonal measures, constructed mostly across soil and water conservation bunds or terraces to safely drain excess water to the neighboring field further downstream:

  open cut: a superficial outlet through the bund; in seasons of less rainfall events closed in order to collect water

  hidden cut: constructed by penetrating the bund or terrace. The penetrated part is filled with stones or with branches; in contrast to the open cut the hidden cut type lets only water passing and filters the soil and manure particles

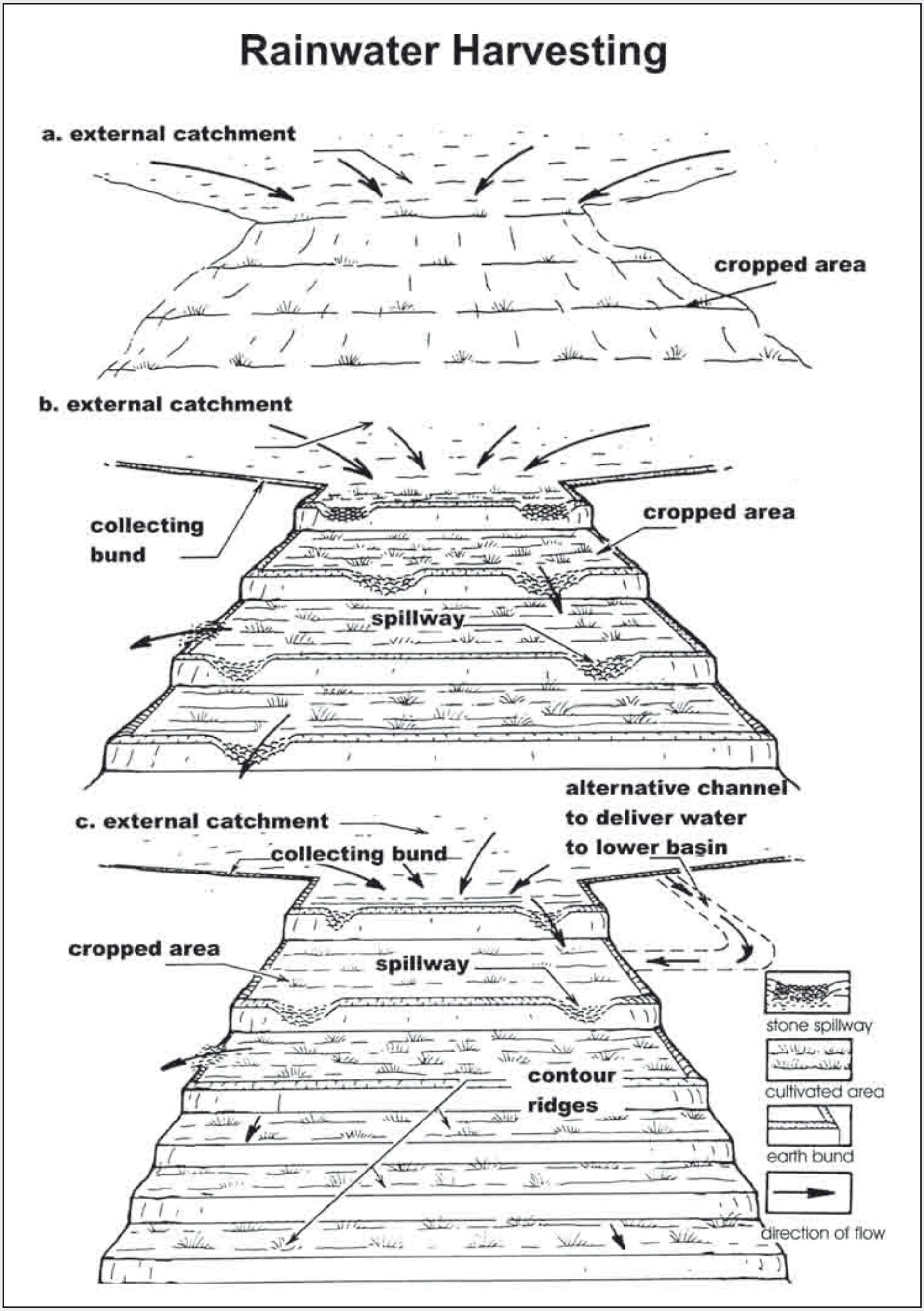


Figure 7.5: Different measures for rainwater harvesting in a terraced area (Source: Pacey and Cullis, 1986)

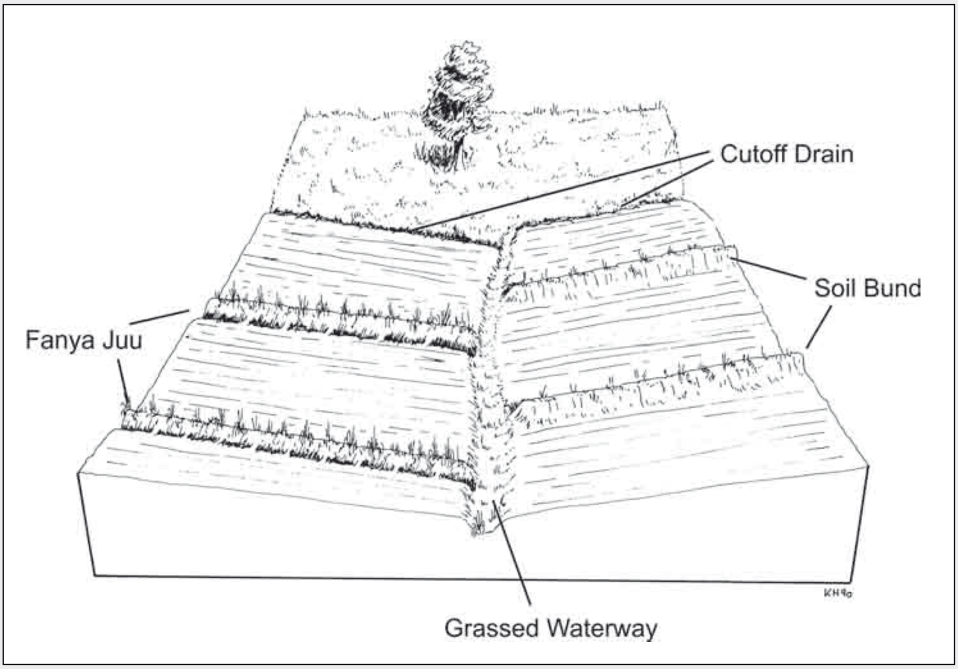


Figure 7.6: Structural SWC drainage systems on a terraced field (Drawing: Karl Herweg)

Potentials, benefits

- Maximum use of limited water (especially important during dry periods; on fields where water availability is low by nature)
- Controlled drainage
- Protection of existing structures (terraces, bunds along contour)

Limitations, weaknesses

- Drainage of excess water to neighboring fields can create damages on subsequent fields and can lead to conflicts among neighbors
- Imperfect design of spillways can lead to gully erosion
- Loss of cropping area, loss of soil for construction of structural measures.

(Source: Gurtner and Stillhardt, 2006; in prep.)

7.4 Agronomic and vegetative SWC measures

The principle of agronomic and vegetative measures is to maintain a high vegetative cover, which serves two purposes: production and protection. An improved crop management can involve improved seeds, appropriate varieties, diverse varieties, optimal timing of planting, appropriate spacing of plants, fertilization, integrated pest and disease management, etc. In addition to improved ground cover, the roots improve soil structure, and thus aeration, infiltration and biological activity in the soil. Plant residues build up soil organic matter and thus improve stability of the soil structure and aggregates. Mixed cropping, inter-cropping, sequential cropping, relay cropping agro-forestry, cover crops, and last not least fallow aim at an optimal plant cover over a longer period of time.

Strip cropping, row cropping, alley cropping, grass strips, hedgerows, and live fences reduce slope length and thus control runoff velocity and allow sediment in solution to accumulate. This process helps to decline the slope gradient and support terrace development. They naturally involve contour plowing and ridging to interrupt long slopes and thus help controlling runoff velocity. But there is the danger that farm implements and machinery increase erosion hazard because they involve compaction of the soil, which prevents infiltration.

Mulching, i.e. a cover of the soil surface by stubbles (stubble mulching), plant residues, manure, compost, and even stones, is a supplement to the above-mentioned SWC measures. Stone mulching not only reduces erosion by decreasing rain splash effect and runoff velocity, but also by conserving moisture under the stones. Recent studies on the effect of stone mulching in Tigray (Nyssen et al., 2001) confirmed these benefits. The weathering of stones enhances also the fertility status of the soils under stone mulch. Depending on the material, mulch reduces the rain splash and controls erosion as other soil cover does. Mulch also minimizes evaporation, a desirable effect in arid areas. In sub-humid areas, however, mulching may also have negative effects on crop production, such as waterlogging, lower infiltration rates and high runoff. Decomposing mulch may lead to a Nitrogen-competition with food crops.

Most soil management practices during seedbed preparation aim at weed control, improved aeration and infiltration. By contrast, minimum tillage or zero tillage tries to avoid any disturbance of the soil structure. Green manure, i.e. plowing-in leguminous plants, involves rapid decomposition and stabilizes soil structure. Soil stabilizers and soil conditioners (organic by-products, synthetic polymers) enhance aggregation of soil and increase infiltration, but they are expensive and hardly accessible.

Compost / manure application

Definition, specifications and purpose
The dimension of a pit for compost formation is about 3 x 4 x 1 m and most of the time it is located near farmers' houses and is filled by collecting goat's, cattle's, donkey's dung, remains of burned materials (like wood, dung, etc.) or ash, useless straws (remains of animal food), garbage (except strong paper and plastic). Some farmers also include also green plant remaining from animal feeding, other fear that this practice leads to a fast distribution of weeds (seeds do not decompose in a compost). The compost is collected in the pit from June to next spring and is then dispersed on fields.

Potentials, benefits
- Better topsoil resistance against erosion (higher content of organic matter, better soil structure)
- Increased crop production application of manure
- Easy to do

Limitations, weaknesses
- A lot of cattle dung is used as fuel what leads to a shortage of manure
- With uncontrolled, free grazing, a lot of dung is distributed randomly over the area and can not be used
- Labor intensive: manure has to be collected from fields

Stone mulching

Definition, specifications and purpose
Stones on fields can be used for mulching. The stones protect the soil surface from evaporation and decrease at the same time runoff velocity of surface runoff

Potentials, benefits
- Hinders evaporation (increased water holding capacity)
- Hinders erosion

Limitations, weaknesses
- Hard workability
- Stone cover has a negative effect on tuber crops (potatoes, onions, garlic)
- Weeding is difficult

Grass strips

Depending on the natural environment, the availability and the ecological need four different types of grass are used for grass strips:

- Elephant (Pennisetum purpureum): a robust perennial grass with a vigorous root system, grows up to a height of 180-360 cm, spreads slowly; dry-matter yield; stands heavy grazing and provides a great bulk of feed; commonly used in a cut-and-carry system.
- Vetiver (Vetiveria zizanioides): tall, stout perennial; stands very heavy grazing; is usually burnt, and the tender young shoots are grazed, the older leaves are too hard for fodder; it has proved useful for erosion control. In addition, the aromatic roots are a source of vetiver oil, used in perfumery; drought resistant.
- Columbus (Sorghum almum): a fast-growing, high-yielding, palatable, short-term summer grass, suitable for quick grazing, to help defray establishment costs; also useful for silage; it has some drought and salinity tolerance.
- Alfalfa (Stylosanthes humilis): a self-regenerating, self-fertile summer-, annual- or short-lived perennial grass; adaptability to soils of low fertility (N-fertilizer); palatability is increasing with age

Potentials, benefits

- Double purpose of Elephant grass, Columbus and Alfalfa: fodder production and SWC; Vetiver is more focused on SWC
- Accumulation of eroded material, increase of soil fertility (along the grass strip)
- Protection against wind erosion, especially when combined with trees or bushes
- Stands heavy grazing

Limitations, weaknesses

- No grazing or cut and carry at least during the establishment phase to protect the young plants against trampling and overgrazing; potentially conflicting with open grazing
- Drought during establishment phase
- Elephant grass is not drought resistant and needs irrigation

Intercropping, mixed cropping

Definition, specifications and purpose

Mixing different crops on one field to reach a better surface cover, as stages of crop development and harvesting are different e.g.:

- Wheat and barley
- Maize and faba beans
- Maize and tomato; maize plants can be used as sticks for the tomato plants

Potentials, benefits
- Minimizes the risk of failures and increases food security in case of insufficient rainfall
- Avoids unbalanced uptake of nutrients
- Nitrogen-fixing function of beans
- Combines production of cattle feed and food for human consumption

Limitations, weaknesses
- Harvesting of crops with different growing rates is difficult (e.g. wheat and barley)
- Requires knowledge about what crops can be mixed

Life barriers / life fences

Definition, specifications and purpose
Trees, bushes, cactus or sisal are planted along roadsides, at settlement borders, along rivers or field borders.

Potentials, benefits
- Stabilizing riverbeds
- Improving soil structure, roots stabilizing soils
- Diminishing slope length
- Trapping sediments, controlling wind erosion
- N-fixation
- Protect the land from animal grazing
- Control of soil erosion, slow down runoff velocity
- Protection against wind erosion

Limitations, weaknesses
- Competition with crops for water and nutrients
- Lack of knowledge about species and effects
- Potential habitat for birds, insects, pests

Irrigation

Definition, specifications and purpose
There are numerous different technologies for crop irrigation, which are not described here in detail. Common to all technologies is, that plants (crops) can be grown in times without sufficient rainwater supply for plant growing. In terms of SWC the effect is a denser plant cover, minimizing the impact of runoff and splash.

Potentials, benefits
- Additional crops can be grown, crop production can start earlier or be extended
- Better soil surface protection against erosion, especially during the onset of the rain

Limitations, weaknesses
- Expensive
- Often lack of water for irrigation
- High evaporation losses
- Requires expert knowledge and external support
- Salinization

Changing land management practices

The prevailing farming system can be optimized in many ways, such as:
- Changing management / intensity, e.g. from grazing to cutting (for stall feeding)
- Changing the degree of mechanization and commercialization, farming inputs, from mono-cropping to a crop rotation system, from mono-cropping to mixed cropping system, from continuous cropping to managed fallow, from open access grazing to controlled access (grazing land, forest land, also access to firewood), from animal herding to fencing, adjusting stocking rates, staged use to minimize exposure (e.g. staged excavation)
- Layout of land use according to the natural and human environment: e.g. exclusion of natural waterways and hazardous areas, separation of grazing types, distribution of water points, salt-licks, livestock pens, dips (grazing land)
- Major change in timing and frequency or intensity of activities: e.g. land preparation, planting, cutting of vegetation, frequency plowing depth, plowing.
- Control or change of composition of plant species: e.g. reducing invasive species, selective clearing, encouraging desired species, controlled burning / residue burning.
- Most management practices during seedbed preparation aim at weed control, improved aeration and higher infiltration. By contrast, minimum tillage or zero tillage tries to avoid any disturbance of the soil structure.
- Green manure, i.e. plowing-in leguminous plants, involves rapid decomposition and stabilizes soil structure.
- Soil stabilizers and soil conditioners (organic by-products, synthetic polymers) enhance soil aggregation and increase infiltration.

(Source: Gurtner and Stillhardt, 2006; in prep.)

7.5 Land use changes

In principle, the less a piece of land is used in accordance with its biophysical setting, the higher are the efforts for SWC. For example, cultivating steep slopes is possible but not sustainable, because soil erosion will be the limiting factor. In such a case, expensive terracing will be necessary to protect the soil from erosion, to collect the necessary water and to maintain the soil fertility. Other limiting factors are for instance, shallow soils on hilltops (limited rooting depth, reduced water and nutrient volume), and wet soils / flooding on valley floors. In such cases, an alternative to costly structural SWC can be a land use change, e.g. from cropland to grassland, or from grassland to forest and bush land through area closure. Such changes, e.g. establishing forested areas and introducing cut and carry systems, have rehabilitated large areas in Tigray through increased biodiversity. The participating communities that benefited collectively decided to close additional areas and manage it as a system of alternative land use (Descheemaeker et. al., 2005; Mitiku and Kindeya, 2002). The beneficiaries of such an arrangement do not only draw their local legislations but also invest in maintaining soil and water structures to sustain the system (Mitiku and Kindeya, 1998).

Land use changes may involve a shift away from cropland to agro forestry, grazing / grass land, or forest land. Permanent area closure is a frequently used measure, combined with both natural regeneration of vegetation and reforestation; it can include:

- Cut and carry
- Periodically controlled grazing (e.g. from May to the beginning of August)
- Wood production
- Used as reforestation area for special purposes like wood for black smiths, construction wood, etc.
- Reclamation of badlands
- Protection of steep slopes

7.6 SWC on non-agricultural land

To protect **forest- and bush land**, basically the same principles of SWC are used as on cropland. **Miscellaneous land**, particularly homesteads, settlement areas, roads and roadsides, embankments, stream banks and shores, need special attention. On the one hand, they need to be protected from soil erosion themselves. On the other hand, they often produce sufficient runoff to damage adjacent cropland and grassland.

Roads, settlements and other areas with sealed surface do not permit intensive plant growth and must therefore be protected with a (structural) drainage system. Steep slopes and embankments are prone to land slopes and slides. Buffer strips of deep rooting trees, shrubs and grasses stabilize the soil and cover the surface. Geo-textile "mulch" is very effective but also expensive and only of temporary character. Structural SWC such as revetment, bank stabilization, slope stabilization or dry walls can provide resistance against river erosion.

7.7 Wind erosion control measures

Wind erosion is a problem of high wind speed, e.g. on plain land, under dry conditions, and without vegetation cover. Increased **surface roughness** (tillage) can decrease the erosion of soil particles. **Rolling** after seedbed preparation increases adhesion of soil aggregates but can also cause compaction. **Windbreaks** such as hedges, life fences and tree shelterbelts can slow down wind velocity and lead to accumulation of eroded material.

7.8 Salinity control measures

Regular leaching using water of low salt content, which will finally be drained, can control salinity. In sodic soils (Na-soils) however, this may affect the soil structure. An alternative provides the Na-exchange, which involves polyvalent salt, such as Gypsum. Gypsum triggers a coagulation of clay, which increases the percentage of macro pores, and water movement in the soil is eased. Parallel, Ca is exchanged against Na, which will be in solution and can be drained.

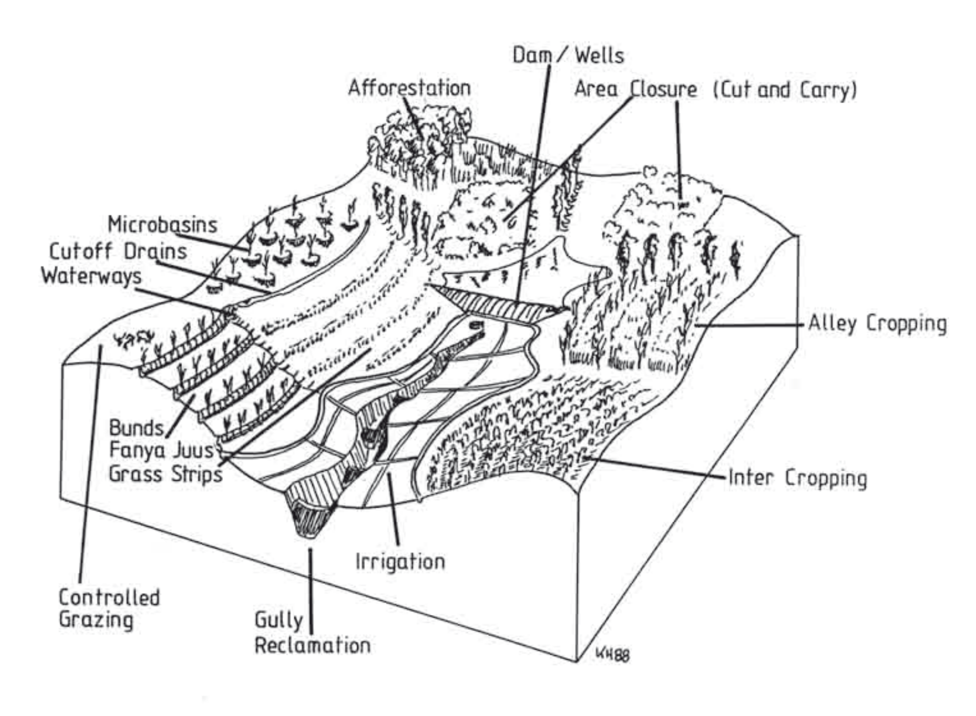


Figure 7.7: A sustainable protection of a landscape always includes different measures to protect the soil, increase the fertility and stabilize the environment (Drawing: Karl Herweg)

7.9 Questions and issues for debate

- Can you imagine important factors influencing the decision for a certain SWC measure, other than those listed in section 7.1?
- On farmers' fields, SWC technologies are mostly a mix of several components (structural, vegetative, agronomic, land use change). Why did we present these technologies separately in this book?
- As a beginner, extension workers have a list of SWC technologies at hand, but the lack experience of what works, what does not work, and why not. Farmers, by contrast, have a lot of experience on their farms, but may be interested to know other technological options. What do you conclude for yourself from that? How can farmers' wealth of experience and your theoretical knowledge be merged best? What do you have to avoid?

8 Assessment of Soil and Water Conservation

8.1 About assessment, criteria and personal perceptions

For quite a long time, soil and water conservation has been considered a more or less technical issue, based on years of dominantly biophysical problem-oriented research on factors such as climate, soils, topography, vegetation, etc. Consequently, many SWC guidelines were published with dominantly technical character (for example: Hudson, 1995; WDLUD, 1995; Schwab et al., 1993; Landon, 1991; Singh, 1991; FAO, 1989; Wenner, 1989; Hurni, 1986; Wenner and Kebede, 1984; Wijntje, 1983; FAO, 1976; USDA, 1975). Much less information is available concerning solution-oriented research including that addresses, among other things, also negative side effects, about the compatibility of technical solutions with prevailing socio-cultural and economic settings of a specific area, and about the process of adapting SWC to such settings (Liniger and Schwilch, 2002).

In the 1980s, SWC in Ethiopia focused on preventing further decline of the remaining soil resources and to rehabilitate already degraded soils. It was most unfortunate that the issue of resource management was split into different tasks addressed by different ministries and departments – e.g. controlling soil erosion (Community Forestry and Soil Conservation Department; SCRP) and agricultural production (Agronomic Development Department, Institute of Agricultural Research) – without appropriate coordination. In the course of the political changes in 1991, Ethiopian farmers began on a large scale, removing and modifying SWC schemes that were previously established by the government under the food for work program. These reactions can be seen as an eye-opener for many SWC experts who had to learn that SWC could only be made effective if it's economic viability and social acceptability is given the same attention as ecological soundness and technical feasibility.

Particularly under subsistence farming, successful SWC interventions faced a common challenge: if the measures were viable for the farmer, they were often insufficiently controlling erosion; if they controlled erosion effectively, they were often too costly and no longer viable, leave alone acceptable. It seems difficult if not impossible to develop standard solutions fulfilling all requirements simultaneously (soundness, feasibility, viability, acceptability). In this context, it should not be forgotten that "assessment" means personal judgment, that farmers and experts have different aims and perceptions, and that they may not always agree on the same assessment criteria! Instead, SWC seems always to be a compromise under the given local conditions.

The following examples are intended to shed light on how SWC measures can be assessed. They also contain a lesson to be learned about the consequences of assessment. Although planned with good intentions, innovative SWC will always produce negative side effects as well. Improving a technology means, therefore, recognizing the strong aspects, admitting mistakes and drawing relevant conclusions. Ignoring side effects to hide own shortcomings means that land users will bear the consequences later on (Fikru et al., 2005).

8.2 Example I: SWC measures under semi-arid conditions

The first example considers soil loss and runoff, two ecological criteria, for assessing different SWC technologies in the semi-arid environment of Afdeyu research site. A double mass curve was chosen as graphic representation, with cumulative soil loss on the Y-axis and cumulative runoff on the X-axis (Figure 8.1). Each dot represents the increase in soil loss / runoff of one rainstorm period. Each graph contains the data for all four experimental plots of one year. The scales differ for each year (Stillhardt et al., 2002), because, if uniform scales are taken, the total amount of runoff and soil loss in relatively dry years is too small to produce a visible picture. This is important to keep in mind when using the graphs to compare different years!

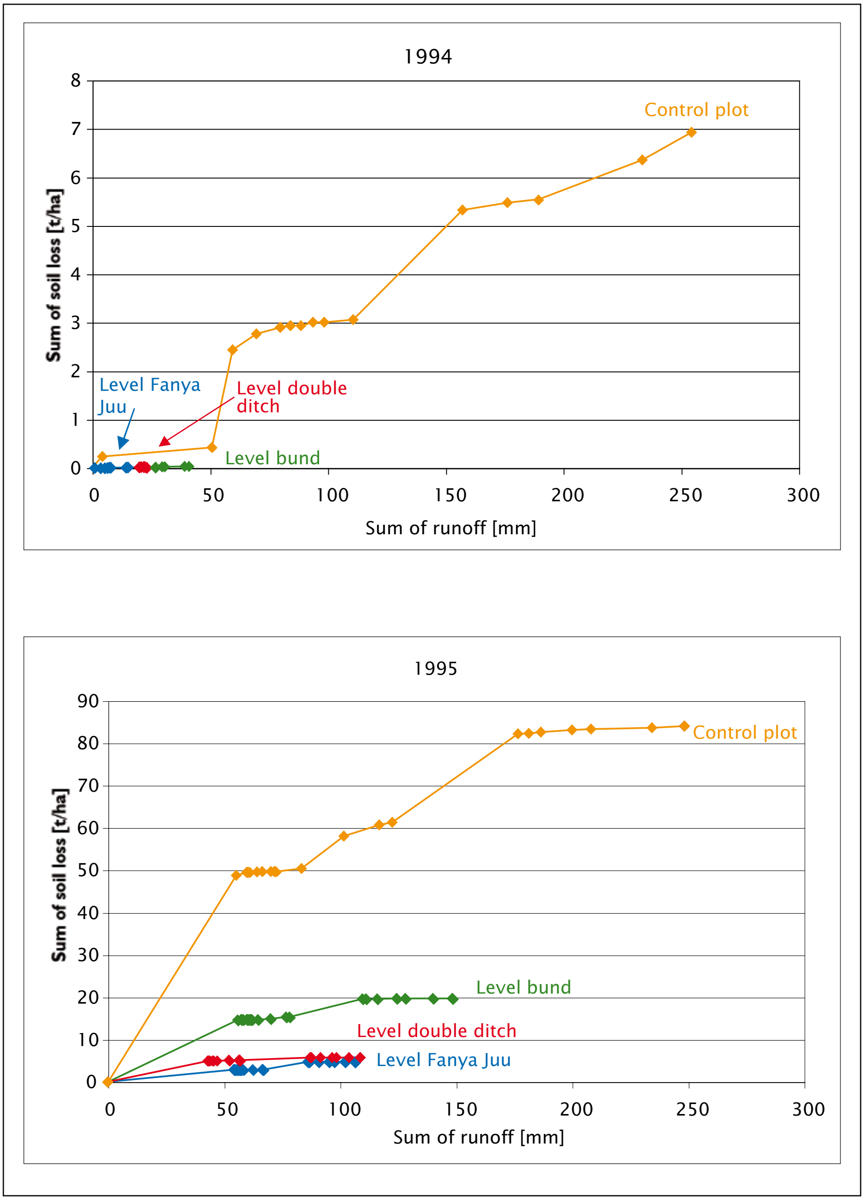


Figure 8.1: Soil loss / runoff of different SWC plots in Afdeyu. Please note, that the scales differ for different years (Source: Stillhardt et al., 2002)

Generally, the control plot (traditional management without specific SWC measure) shows always the highest runoff and soil loss values. Only during the two dry years 1989 and 1990 the loss from the level bund plot was slightly and negligibly higher.

Table 8.1: Ranking of different SWC measures in Afdeyu (Source: Stillhardt et al., 2002)

Year	Control plot		Level bund		Level *Fanya Juu*		Level double ditch	
	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff	Soil loss	Runoff
1989	2	2	1	1	3	3	4	4
1990	2	2	1	1	4	4	3	3
1994	1	1	4	2	4	3	4	4
1995	1	1	2	2	4	4	3	3
1996	1	1	2	2	4	4	3	3
1997	1	1	2	2	3	4	4	4
1998	1	1	2	2	3	3	4	4
Total	9	9	14	12	25	25	25	25
Rank	1	1	2	2	4	4	4	4

Ranking of each plot compared to the other plots from 1 (highest soil loss or runoff = weakest erosion control) to 4 (lowest soil loss or runoff = strongest erosion control)

In Table 8.1, soil loss and runoff are ranked plot-wise for each year. The lowest soil loss and runoff indicates the strongest erosion control and corresponds with the highest rank (4). The results show that in the environment of Afdeyu all SWC measures are able to reduce runoff and soil loss considerably. "Level *Fanya Juu*" and "level double ditch" show very similar effects and are more effective than "level bund". Considering only these two ecological criteria, *Fanya Juu* and double ditch would be recommended.

However, taking farmers perceptions and experience into consideration, the choice might look completely different. According to Awet and Bereket (1999), about 98% of the cultivated land in Afdeyu is conserved with structural SWC, and each structure occupies a certain area that temporarily does not produce crops. About 75% of the farmers state, that "level bund" would be their favorite out of the three SWC measures offered. The main reason for their preference is that the loss of productive area (14%) of level bund (Semere, 1998) is smaller than the one of *Fanya Juu* (17%) and double ditch (24%). Additional costs of, and lack of experience with, *Fanya Juu* and double ditch are other reasons to prefer bunds.

8.3 Example II: on- and off-site effects of tied ridges

In 1997 stone bunds with tied ridges were introduced to Afdeyu, implemented through campaign with remarkable area coverage. After implementation of the tied ridges, the runoff coefficient at the catchment decreased from 12% to about 6%, indicating that 50% of the former discharge was additionally stored within the catchment. Also the sediment yield was lowered considerably. At the same time, a small irrigation dam was planned downstream. The impacts of the tied ridges on the dam appeared to be conflicting. On the one hand, on-site tied ridges reduce soil loss, which prevents the dam from being silted up soon. On the other hand, on-site SWC also reduces river discharge by about 50% thus lowering the expected water storage and reducing the irrigation potential of the dam (Table 8.2).

Table 8.2: Hydrological data as assessed for a dam volume planning in Afdeyu (Source: Burtscher 2002)

Year	Cumulative Discharge River Gauge m^3	Expected Storage Planned Dam m^3	Modeled Level of Lake Surface m	Cumulative Precipitation mm	Runoff Coefficient River Gauge %
1986	81668	110494	16.4	488	9.4
1987	79672	110952	16.5	397	11.3
1988	138750	206609	19.4	606	12.9
1996	122794	178053	18.8	552	12.6
1999	69748	98369	15.9	598	6.6
2000	49953	69352	14.5	527	5.4

Depending on the interests of stakeholders, the effect of the tied ridges may be assessed differently. Farmers in the upper part of the catchment might give a positive judgment because the (on-site) effect of tied ridges increases the amount of available water and production on their cropland. Farmers who irrigate land below the dam would probably make a negative assessment because the (off-site) effect of SWC reduces the amount of irrigation water.

8.4 Example III: comprehensive assessment of selected soil and water conservation measures

The main SWC measures monitored by the SCRP on cultivated land were the soil (or stone) bund and the *Fanya Juu* type terrace (Herweg and Ludi, 1999). Both technologies consist of a small dam and a ditch. To construct a bund, the excavated material of the ditch is moved “downhill” to build a dam; the term „*Fanya Juu*“ is the Swahili expression for „throw uphill“ (cf. Figure 8.2). With on-going soil erosion and accumulation, both measures eventually build up to bench terraces. The *Fanya Juu* was developed in Kenya as a modified form of the contour terrace (Bergsma, 1996). Both measures have been widely implemented on small, labor-intensive farms (Bergsma, 1996), but not without adaptation problems (Kamar, 1998). The particular attractiveness of the *Fanya Juu* is that level terraces can develop in as little as seven years (Hudson, 1988).

While implementing structural SWC in Ethiopia and Eritrea, three assumptions were commonly made: (1) without SWC, erosion would decrease production in the long run; (2) with SWC, production would stabilize or increase; (3) the expected stabilization or increase in production would be an incentive in itself for farmers to maintain SWC structures. However, a different development was observed following political changes in 1991, when government control over the rural population diminished (Herweg, 1992b). As long as there was an incentive (e.g. food for work), this additional source of income secured the livelihood of the local communities (Kebede, 1992). Consequently, many farmers tolerated imposed SWC structures on their land. In many semi-arid areas, maintenance of SWC structures implies short-term benefits for farmers because moisture conservation directly enhances crop production. In some parts of the sub-humid highlands (e.g. Welayta, Hararghe), a partial modification of SWC and integration into the complex indigenous land management system was observed, while in other parts (e.g. Kembata and Northern Shewa) a considerable number of SWC structures were – at least temporarily – removed in the early 1990s.

8.4.1 Methodology

At each research site one block of four to six plots on-farm were established in order to test three to five SWC measures (Figure 8.2) against the respective local cultivation practice of the farmer (control plot). Each plot or treatment accommodates two or three SWC structures on an area 6 m wide and 30 m long. A block with 6 plots measured 36 m x 30 m. The replication of such a block is not possible for several reasons. On the one hand, due to the rugged highland topography, soil properties and slope angles change on a small scale. On the other hand, farm size is on average below one ha, so that a replication would involve different farmers, crop rotations, and farm operations. Thus, under the present set-up, the inherent variations of each plot cannot be investigated. All plots are constructed with removable borders to allow uniform tillage and crop rotation on the entire block. The concerned farmer determines the crop rotation and timing of farm operations.

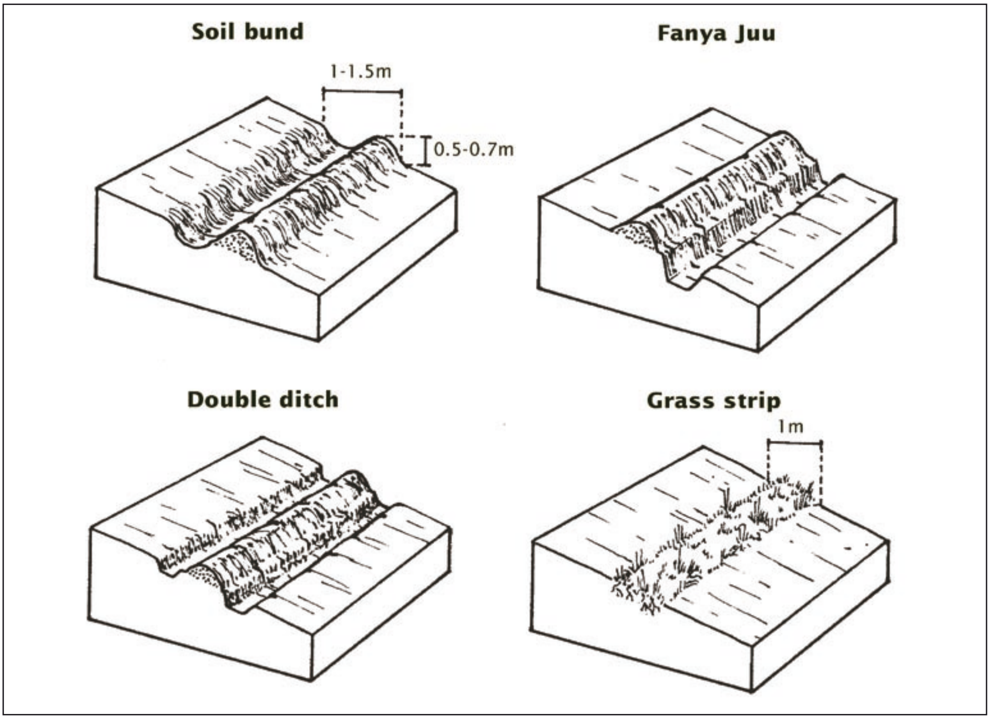


Figure 8.2: SWC measures tested at the SCRP research sites - cross-sections in the construction stage (Source: Herweg and Ludi, 1999)

Fanya Juu and soil / stone bunds are the terrace types that are most widely implemented in the highlands of Ethiopia. At some research sites, both types were tested in two variations: level (on the contour) and graded (with a gradient of about 5% for drainage of excess water). In addition, grass strips were newly introduced in the experiment as a more cost-effective practice. In the semi-arid area of Afdeyu (Eritrea), the level double ditch that was designed to enhance moisture conservation replaced the grass strip in the experiment. A range of systematic and random data errors, parameter estimation errors, and model errors determines the accuracy of soil loss and runoff values (Herweg and Ostrowski, 1997). For single erosion periods, data accuracy ranges between ± 2-5% for runoff and ± 6-16% for soil loss, respectively. The accuracy of annual data, in contrast, improves to ± 0.1% for runoff and - 3% for soil loss, respectively.

Production data are computed from the harvest of the entire plot area. After the measurement, grain and biomass are returned to the farmer. In comparison with the control plot, the area of actual production on treated plots is reduced because SWC structures occupy about 10% of the plot. The production data of the entire plot (180 m2) thus reflect the net harvest for the farmer, both with SWC (on treated plots) and without SWC (on the control plot).

8.4.2 Results

With regard to SWC, the SCRP research sites were grouped in three classes (Table 8.3):

- Semi-arid areas, with a mean annual precipitation below 500 mm and a mean annual erosivity below 300 J/m·h, where priority is given to water conservation (Afdeyu);
- Sub-humid areas, with unreliable rainfall, a mean annual precipitation between 500 and 1300 mm and a mean annual erosivity between 300 and 500 J/m·h, where both soil conservation and water retention are important (Maybar, Hunde Lafto);
- Sub-humid areas, with reliable high rainfall, a mean annual precipitation above 1300 mm and a mean annual erosivity above 500 J/m·h, where priority is given to soil conservation and drainage of excess water (Andit Tid, Anjeni, Gununo, Dizi).

Table 8.3: SWC-oriented classification of the research sites (Source: Herweg and Ludi, 1999)

Research site	**SWC-Class**		**Annual Precipitation**			**Mean annual erosivity**	**Dry season in winter***
			Mean	**Standard deviation**	**Coefficient of variation**		
			mm	**mm**	**%**	**J/m·h**	**months**
Afdeyu	1	semi-arid	382.3	106.8	29	230	9
Hunde Lafto	2	sub-humid with insecure rainfall	935.1	205.1	22	346	5
Maybar	2		1‘210.9	247.4	20	420	4
Andit Tid	3	sub-humid with secure high rainfall	1‘357.9	242.6	18	506	4
Anjeni	3		1‘690.0	154.8	9	633	5
Gununo	3		1‘314.3	255.4	19	582	3
Dizi	3		1‘512.1	124.1	8	646	4

** Mean Monthly Precipitation less than 50 mm*

Period of Observation: Af 1985-90; Hu 1983-90; 93; Ma 1982-89; 92-93; At 1983-92; Aj 1985-90; 92-93; Gu 1982-92; Di 1989-93; Interruptions are due to war and instability

Before interpreting the results, the criteria and the desired impacts have to be defined (Table 8.4). Except for runoff, the desired impact is obvious: production should increase and soil loss should decrease. Runoff, in contrast, is a more complicated issue and needs careful evaluation! Less runoff results in lower soil loss rates, but at the same time it may cause waterlogging on terraced land, particularly in high rainfall areas, which affects production of certain crop types as well as the adaptation of the technology. Thus in semi-arid areas, runoff reduction is desirable, while in the sub-humid areas it should not or only slightly be reduced.

Table 8.4: The desired impact of SWC measures on different variables

Criteria	Desired impact
Crop yield	increase
Biomass	increase
Soil loss	decrease
Runoff	▪ decrease for semi-arid areas ▪ slight or no decrease for sub-humid areas due to waterlogging hazard (maximum 10% decrease from control plot)

The results discussed below were obtained from experimental plots (EP, 6 m x 30 m) and are, interestingly, not always corresponding with the results obtained from test plots (2 m x 15 m) observed on shorter slopes and during a longer observation period (cf. Chapter 4)! The mean annual soil loss and runoff values of EPs (Tables 8.5, 8.6, 8.7) reveal a comparatively low erosion hazard in sub-humid areas with insecure rainfall (Hunde Lafto, Maybar, SWC-class 2), while relatively high erosion rates are measured in semi-arid conditions (Afdeyu, SWC-class 1). Relatively high erosion rates were observed in sub-humid areas with secure high rainfall located at higher altitudes (Andit Tid, Anjeni, SWC-class 3). Despite high annual rainfall and erosivity, low soil loss rates were measured in Gununo and Dizi (SWC-class 3), where the lower altitude implies a more moderate temperature, higher biodiversity, and a more rapid development of protective ground cover.

To assess the impact of the SWC treatments, soil loss, runoff, crop yield and biomass values of the respective control practice were set at 100%. For each treatment the reduction or increase was calculated in %, compared to the control plot (Table 8.7). It should be noted that this analysis was restricted to the average effects over the entire period of observation.

Table 8.5: Annual soil loss and runoff under local cultivation practices (Source: Herweg and Ludi, 1999)

Research site	Soil type (Slope %)	Soil Erosion under local cultivation practice				Years of soil loss / runoff measurement	No of crop yield / biomass measurements*
		Annual runoff mm Mean (range)	Annual soil loss t/h				
			Mean (range)	Standard deviation	Coefficient of variation %		
Afdeyu	shallow stony Cambisol (31)	161.5 (34.3-359.3)	42.0 (3.1-114.3)	51	122	3	–
Hunde Lafto	pellic Vertisol (21)	12.1 (0.8-18.2)	7.2 (0-16.3)	7	95	3	7
Maybar	haplic Phaeozem (28)	24.7 (16.9-29.9)	1.9 (0.7-3.7)	1	61	4	7
Andit Tid	eutric Regosol (24)	354.2 (183.2-687.9)	48.4 (2.1-139.9)	50	104	5	5
Anjeni I**	vertic Luvisol (28)	486.6 (358.5-619.9)	110.1 (59.2-167.1)	29	26	grass strip 3, others 5	grass strip 3, others 7
Anjeni II**	eutric Nitosol (12)	482.3 (365.0-645.0)	90.4 (16.5-175.5)	69	76	grass strip 3, others 5	grass strip 4, others 10
Gununo	humic Nitosol (14)	131.0 (50.0-261.9)	11.4 (0.8-22.0)	8	71	5	6
Dizi	haplic Lixisol (18)	45.2 (9.1-138.6)	5.1 (0-24.8)	10	195	5	6

** There may be more than one harvest per year*
*** Anjeni contains two experimental set-ups on 28% and 12% slopes, respectively*

Table 8.6: Mean annual soil loss and runoff for different SWC measures and local cultivation practices (Source: Herweg and Ludi, 1999)

Mean annual soil loss (t/ha)						
Research site	**Local cultivation practice (control)**	**Graded *Fanya Juu***	**Graded bund**	**Grass strip (double ditch in Af)**	**Level *Fanya Juu***	**Level bund**
Afdeyu (Af)*	42.0	–	–	8.0	7.2	13.8
Hunde Lafto (Hu)	7.2	3.3	2.4	2.9	0.0	0.0
Maybar (Ma)	1.9	1.8	3.3	0.9	0.5	1.2
Andit Tid (At)	48.4	17.8	28.7	13.0	6.0	6.9
Anjeni I 28% (Aj)	110.1	35.6	37.9	–	–	–
Anjeni II 12% (Aj)	90.4	17.1	33.5	–	–	–
Gununo (Gu)	11.4	0.8	1.3	1.9	0.2	0.3
Dizi (Di)	5.1	0.5	0.7	1.5	0.8	0.2
Mean annual runoff (mm)						
Station	**Local cultivation practice (control)**	**Graded *Fanya Juu***	**Graded bund**	**Grass strip (double ditch in Af)**	**Level *Fanya Juu***	**Level bund**
Afdeyu (Af)*	161.5	–	–	86.8	63.8	85.1
Hunde Lafto (Hu)	12.1	20.0	15.9	6.6	0.6	0.7
Maybar (Ma)	24.7	26.7	36.1	16.7	12.8	18.5
Andit Tid (At)	354.2	348.1	335.2	236.2	193.9	132.9
Anjeni I 28% (Aj)	486.6	324.6	331.0	–	–	–
Anjeni II 12% (Aj)	482.3	239.3	289.7	–	–	–
Gununo (Gu)	131.0	38.0	61.8	58.3	9.3	19.8
Dizi (Di)	45.2	18.3	27.2	19.6	32.3	15.3

Table 8.7: The average impact of SWC measures on soil loss, runoff, crop yield and biomass compared with local cultivation practices

Research site	Relative impact on soil loss (%)					Relative impact on runoff (%)				
	Graded ***Fanya Juu***	Graded bund	Grass strip**	Level ***Fanya Juu***	Level bund	Graded ***Fanya Juu***	Graded bund	Grass strip**	Level ***Fanya Juu***	Level bund
Afdeyu **	–	–	-81 w	-83 w	-67 w	–	–	-46*	-60	-47
Hunde Lafto	-54	-67 w	-60 w	-100 w	-100 w	+65	+31	-45	-95	-94
Maybar	-4	+73 w	-55 w	-72 w	-37 w	+8	+46	-33	-48	-25
Andit Tid	-63 w	-41 w	-73 w	–	–	-2	-5	-33	–	–
Anjeni I 28%	-68 w	-66 w	-72 w	–	–	-33	-32	-41	–	–
Anjeni II 12%	-81 w	-63 w	-57 w	–	–	-50	-40	-19	–	–
Gununo	-93 w	-88 w	-84 w	–	–	-71	-53	-55	–	–
Dizi	-91 w	-87 w	-71 w	–	–	-59	-40	-57	–	–

Research site	Relative impact on crop yield production (%)****					Relative impact on biomass production (%)****				
	Graded ***Fanya Juu***	Graded bund	Grass strip	Level ***Fanya Juu***	Level bund	Graded ***Fanya Juu***	Graded bund	Grass strip	Level ***Fanya Juu***	Level bund
Afdeyu ***	–	–	–	–	–	–	–	–	–	–
Hunde Lafto	+7	+15	-4	+4	+12	+6	-2	+7	+7	+12
Maybar	-22	-27	-24	-28	-30	-22	-25	-27	-26	–26
Andit Tid	-50	-12	-39	–	–	-45	-11	-37	–	–
Anjeni I 28%	+4	-13	0	–	–	-5	-13	+8	–	–
Anjeni II 12%	+14	-6	+14	–	–	+5	-12	+11	–	–
Gununo	+13	+5	+16	–	–	+22	+12	+16	–	–
Dizi	-17	-39	-20	–	–	+2	-22	-18	–	–

**Period of observation: Af: 1988-90; Hu: 1989-90, 93; Ma: 1986-89; At: 1987-91; Aj: 1986-90, 92; Gu: 1987-91; Di: 1989-93*
*** In Afdeyu, the level double ditch replaced the grass strip*
**** In Afdeyu, the farmer decided to leave all plots fallow*
***** The area for yield and biomass measurement is always the entire plot (180 m^2)*
Significant difference at $p < 0.05$ for soil loss using Wilcoxon Signed Rank Test
Shading indicates whether the desired impact (increase/decrease, +/-) was achieved

(Source: Herweg and Ludi, 1999)

8.4.3 The ecological dimension: soil loss and runoff

Significance was tested only for soil loss as the most important indicator in the study. The Wilcoxon Signed Rank Test ($p < 0.05$) showed significantly smaller soil losses for the majority of SWC treatments when compared with the respective local cultivation practices (control site). But there are no significant soil loss differences between most SWC treatments, and so there is no „best“ measure as such (Table 8.7). Despite this considerable soil loss reduction, absolute erosion rates can still be very high, even under SWC. More than 30 t/ha in Anjeni, 10 t/ha in Andit Tid, and 7 t/ha in Afdeyu were recorded on EPs in single years. A considerable proportion of these annual values were caused during a few rainfall periods. As much as 10 t/ha (Andit Tid), 6 t/ha (Hunde Lafto, Anjeni) and 1 t/ha (Gununo, Dizi, Maybar, Afdeyu) of soil loss were observed during single periods, encompassing between one and three rainstorms. Therefore, absolute soil erosion rates might still be above a given tolerance level and call for further improvement of SWC technologies.

Runoff was considerably reduced at the semi-arid site of Afdeyu (SWC-Class 1) and thus the goal of moisture conservation was met. For SWC-Class 2 (Maybar, Hunde Lafto), the impact of SWC on runoff reflects a potential dilemma. On the one hand, graded structures increase runoff. This may cause erosion of the drainage ditches during seasons with high rainfall, while precious moisture may be lost during cropping seasons with sub-average rainfall. On the other hand, level structures decrease runoff, which is desirable in times of moisture stress but increases the probability of waterlogging and breakage of SWC structures during high rainfall periods. For SWC-class 3, runoff reduction is generally considered high in view of the increased waterlogging hazard (Figure 8.3, Table 8.8).

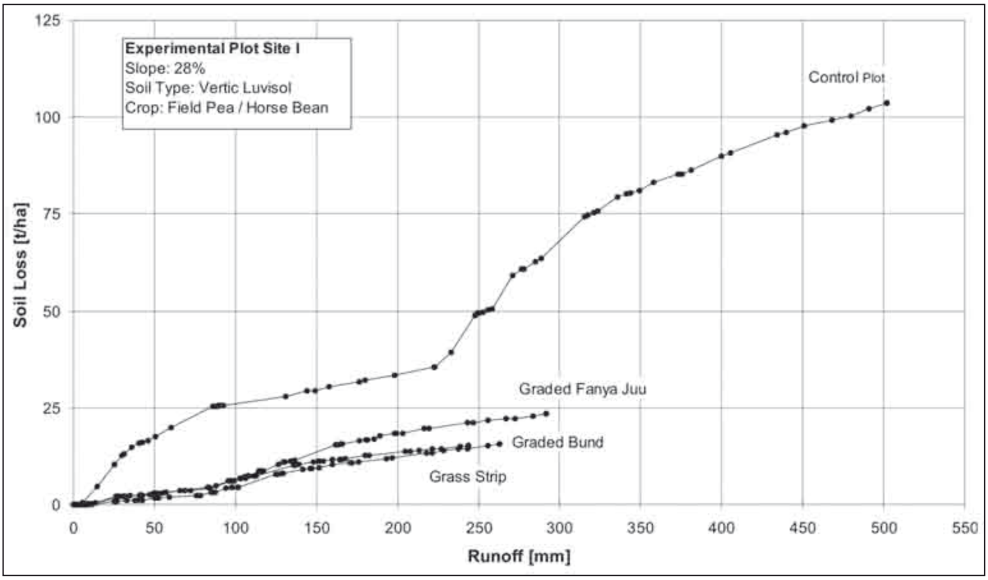


Figure 8.3: Cumulative soil loss and runoff on a 28% slope in Anjeni, 1990

The impacts of graded Fanya Juu, graded bund and grass strip on soil loss and runoff are represented with a double mass curve. In the absence of replications, it is not possible to postulate significant differences between the SWC measures. But there is considerable soil loss reduction by all treatments compared to the control plot. The reduction in runoff, on the other hand, point at an increasing waterlogging hazard in Anjeni, which affects crops such as barley and beans. (Source: Herweg and Ludi, 1999)

Table 8.8: Absolute and relative annual soil loss and runoff on a 28% slope in Anjeni, 1990

Experimental plot Anjeni I, 28% slope					
		Local Cultivation Practice (Control)	**Grass strip**	**Graded *Fanya Juu***	**Graded bund**
Soil loss (absolute)	t/ha	104	16	23	15
Soil loss (relative)*	%	100	15.4	22.1	14.4
Runoff (absolute)	mm	502	263	292	244
Runoff (relative)*	%	100	52.4	58.2	48.6

** In relation to the control plot values, which are set at 100% (Source: Herweg and Ludi, 1999)*

8.4.4 The socio-economic dimension: crop production, viability and acceptability

The on-farm experiments (EP) involved only structural measures but no additional agronomic or vegetative techniques. So it is not surprising that, in contrast to the assumptions explained in the introduction, production – the most important factor for farmers – rarely increased during the first three to five years after the implementation of SWC. However, except for Andit Tid and Dizi (SWC-class 3), total crop production remained relatively stable, which is reflected by only slight changes (decrease / increase) in crop yield and biomass of treated plots compared with the control site.

Some of the factors influencing the social acceptability of an introduced SWC measure are, for example, legislation, national, regional and local policy, land ownership, availability and quality of extension services, financial support, access to markets and information, integrability in a traditional land management system, availability of labor force, planning horizon, traditional norms and values, religious or social taboos, local power structures, leadership, local interrelations and group work, availability of alternatives, technical skills, health status, etc. Some of these factors might influence all farmers in a certain area in a similar way, but normally different stakeholders have several and even competing interests (according to their assets). Such complex situations are not easy to understand and difficult to manage. Prediction of what might happen is almost impossible but can be monitored during or after implementation.

SWC structures can have entirely different – even controversial – effects and consequently a different degree of adaptation if they are transferred to other biophysical and/or socio-economic conditions (Herweg, 1995). Even a SWC measure that most efficiently controls erosion somewhere else may not be worth the effort of implementation if local farmers cannot accept it. The social dimension of sustainability can only be assessed through interviews and discussions with local stakeholders. At a first glance from outside, the so-called social acceptability often seems to lack rationality. But the problem is rather that the logic of an external natural scientist or engineer might remarkably differ from the logic of a local farmer. Especially when uniform top-down approaches are used for implementation of SWC the local knowledge is not included in the planning process and there is not much effort of explaining newly introduced measures.

Qualitative observations and statements of farmers from within and in the surroundings of the research sites supplemented the results from the on-farm experiment. In particular, farmers in areas of secure high rainfall (SWC-class 3) had serious complaints about structural conservation (Ludi, 1997; Belay, 1992). Many of these complaints reflect the economic dimension, i.e. effects directly or indirectly affecting crop production. Others refer to the social dimension, i.e. the problems of integrating newly introduced measures into the prevailing farming system, which are often consequences of economic problems. Together, they point at difficulties to manage the social aspect of acceptability of SWC. The main arguments are that:

- SWC structures occupy precious cropping area;
- the area occupied by SWC structures is not plowed, weeds and rodent habitats are no longer destroyed, and cultivated fields are infested.
- despite a drainage gradient of 2% or higher, waterlogging is frequently observed above SWC structures;
- maintenance requires unacceptable labor inputs;
- farmers have problems carrying out their traditional farm operations. Narrow terrace spacing makes it difficult or impossible to plow the slope in diagonal lines and turn the ox-drawn plow.

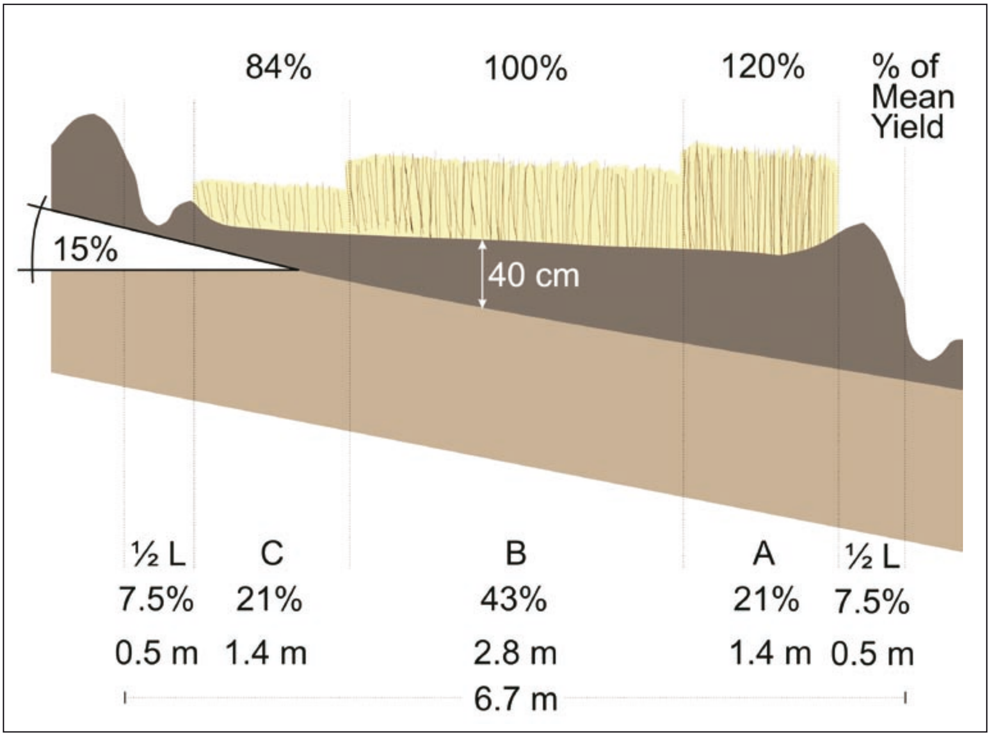


Figure 8.4: Potential impact of changing topsoil depth of a Fanya Juu on crop production (Source: Ludi, 2004; drawing: Karl Herweg)

Within a treated field production patterns can change considerably, as a detailed study of Ludi (2004) in Anjeni shows (Figure 8.4). Under both the soil bund and the *Fanya Juu* type terrace, the lowest crop yield is measured below the structure. A change in the soil profile and increasing spatial variability of soil fertility are considered the major reasons for this. In the course of the erosion process that forms the terrace, the topsoil below the structure is gradually moved downslope and accumulates above the next SWC structure (Krüger, 1994, Figure 8.5). This process is accelerated through tillage erosion, particularly under hoe cultivation (Turkelboom et al., 1997), and less when using the Ethiopian ox-plow, "Maresha", that merely scratches the surface (Nyssen et al., 2000b). If the topsoil is completely eroded, the subsoil will also move downslope on top of the fertile accumulation.

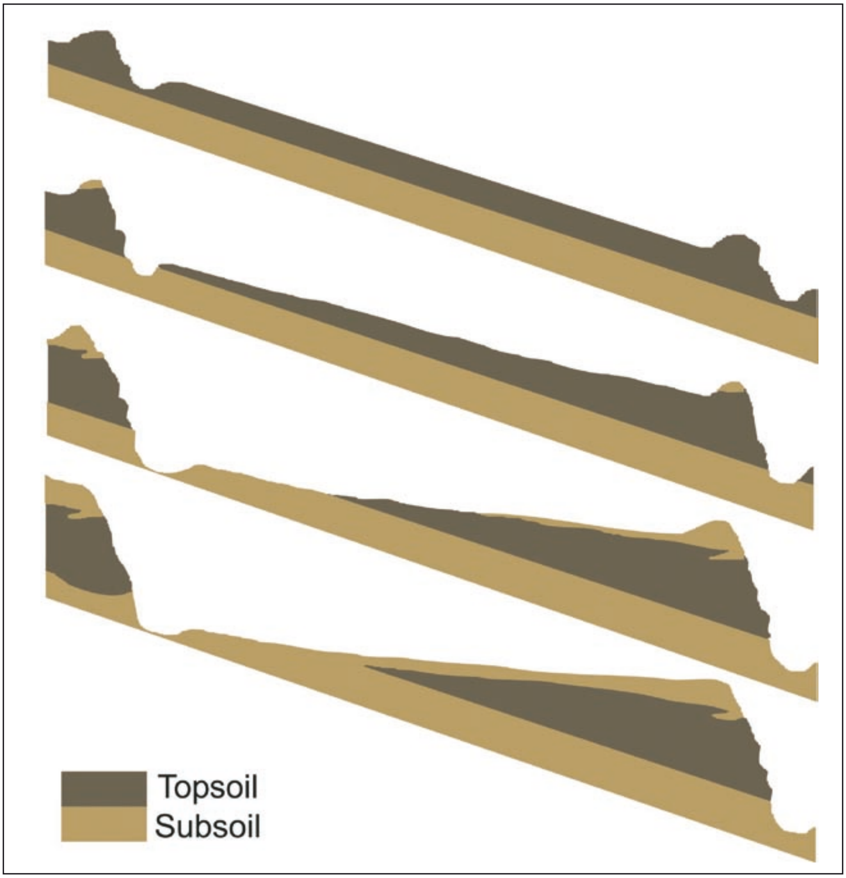


Figure 8.5: Soil profile changes and reduction of production area on a Fanya Juu terrace (Source: Krüger, 1994; drawing: Karl Herweg)

Given an average terrace spacing of 10 m and a *Fanya Juu* width of 1.5 m, for example, 15% of the total area would be out of crop production during the first years (Figure 8.6). On an additional 10 to 15% of the area, production may be affected by waterlogging above the structure, and weeds and rodents both above and below the structure. The area of limited production increases on steeper slopes with narrow spacing. In the long run, it may slightly decrease as the terraces develop and the width of the structures is slightly reduced by farm operations. Although the SWC structure itself can be used for fodder and woody biomass production, this can hardly replace the loss of food production for a subsistence farmer.

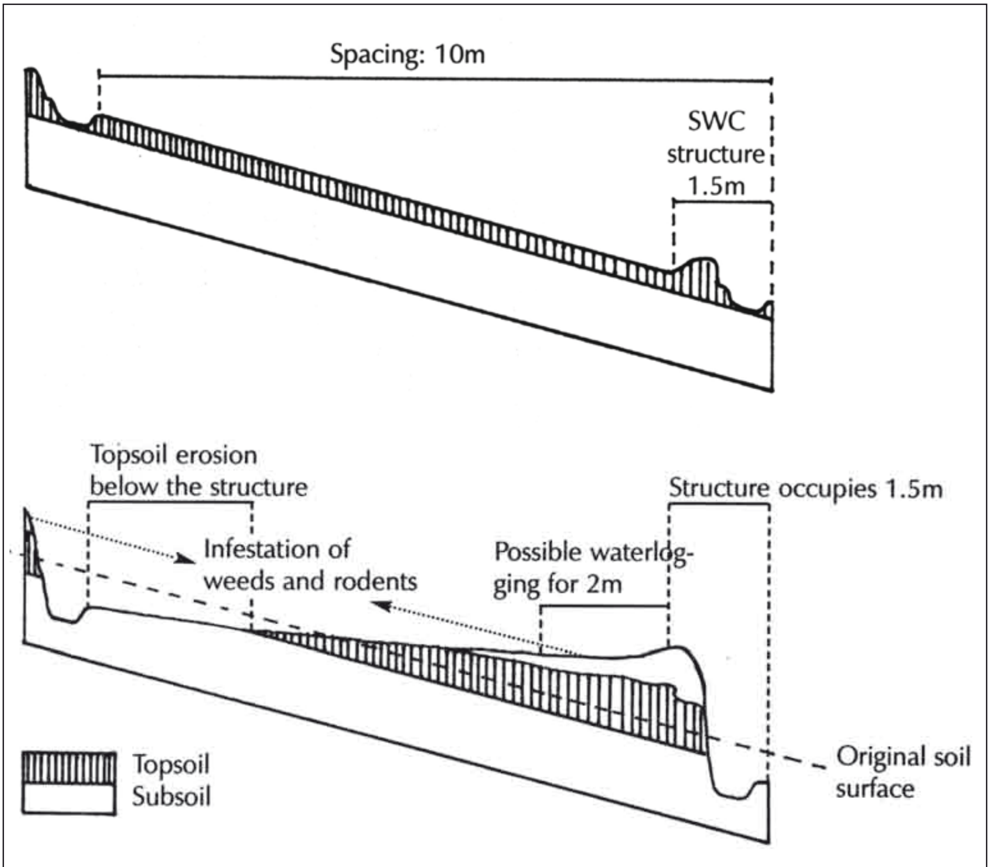


Figure 8.6: Construction, development and side effects of a Fanya Juu (Drawing: Karl Herweg)

Another aspect of acceptability refers to the implications different SWC structures have with respect to labor input and the utilization of fertile soil accumulation (Figure 8.7). On the one hand, the "soil bund" requires less labor input because the excavated material from the ditch is thrown downhill. However, accumulations of fertile topsoil may block the drainage and eventually cause waterlogging or be eroded. Moreover, instead of being used for food production, accumulations are used to raise the bund during maintenance in the following year. On the other hand, drainage of the "*Fanya Juu*" is much less disturbed by accumulated material, and the dam is mainly built from subsoil material. But establishing and maintaining a *Fanya Juu* is much more labor intensive since soil must be moved uphill. Finally, the "grass strip" does not require high labor input since it does not involve moving soil to raise the structure. It drains well because water can penetrate the entire strip. However, terrace development takes longer compared to the other SWC structures.

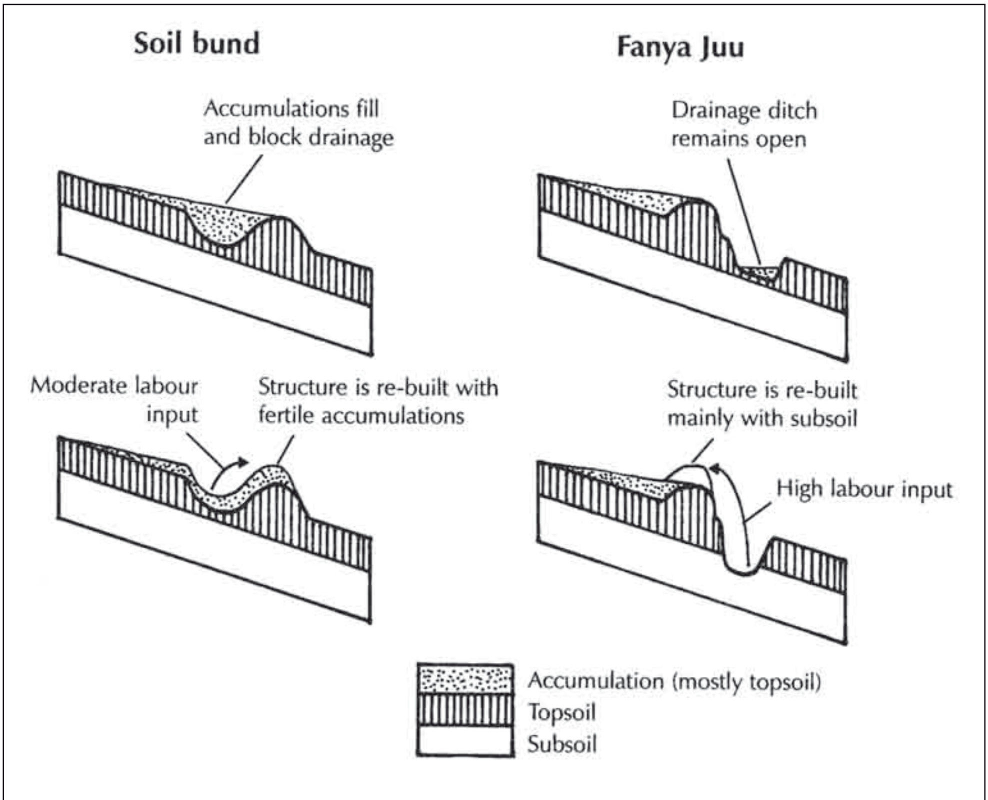


Figure 8.7: Differences in terrace development with soil bunds and Fanya Juu (Drawing: Karl Herweg)

8.4.5 The technical dimension: ill-design and malfunctioning

Attention is rarely given to site-specific characteristics when entire catchments are being conserved through SWC campaigns. The uniform layout of the SWC structures and the inflexibility of untrained extension staff – often paired with unwillingness to maintain SWC structures – literally "invite" technical problems (Photo 8.2). There are uncounted effects of ill-designed or badly maintained structures and their effect on lower lying areas. Most often, the signs are easily visible on the field (Photo 8.1). Signs of unsustainability that can help to understand and assess a specific situation are discussed in Chapter 9. For example a diminishing drainage gradient helps concentrate water and erosion forces at the weakest point of the SWC structures and finally leads to the breakage of structures.

Photo 8.1: An example of failure of SWC structures in Kembata, Ethiopia

Erosion rills developed on the entire slope despite intensive structural SWC. Interestingly, only the life fence in the lower part of the photo seems capable to stop erosion (Photo: Karl Herweg 1989).

Photo 8.2: Ill-designed SWC scheme – lack of skills and experience
Under the same slope conditions (e.g. soil depth, slope angle), using the same SWC guidelines with the same formula of calculating the spacing between SWC structures, inexperienced extension workers came up with an entirely different outline of terraces. It is obvious that Kembata farmers whose fields were heavily dissected by the terraces did probably not appreciate this output. (Photo: Karl Herweg 1989)

8.4.6 Conclusions

Taking the above mentioned results of the study on effects of SWC measures into consideration, a clear-cut recommendation of one "best" SWC technology seems somewhat inappropriate. Instead, the pros and cons have to be carefully weighed against each other, and the final decision which of the advantages and disadvantages of each measure would be acceptable should be left to the land user who has to bear the consequences of SWC.

In general, the reduction of soil loss was considerable at all SCRP stations and with most SWC measures, although absolute erosion rates were still high in some cases. Runoff control, by contrast, requires greater emphasis during the design of SWC structures:

- SWC-Class 1: In semi-arid areas (e.g. Afdeyu), level SWC structures performed well in conserving moisture. However, in Lesotho, Wenner (1989) found that many large rills and gullies developed because of level terracing. He therefore refrains from advocating level earth terraces in general. Instead, such terraces could be improved as described for SWC-Class 2.

- SWC-Class 2: Sub-humid areas with insecure rainfall (e.g. Maybar, Hunde Lafto) are principally subject to both extremes: excess and shortage of water can follow each other closely. In this case, SWC aims to achieve a compromise. Since there is always a probability of excess rainfall, SWC structures need a gradient and waterways, or be breakable during high rainfall events. To ensure water retention during dry spells, supplementary structures such as tied ridges can be useful. Wenner (1989) suggests adding small ditches in the middle of the production area parallel to the SWC structures to increase infiltration and to decrease overtopping of the structures.
- SWC-Class 3: For sub-humid areas with secure high rainfall (e.g. Dizi, Gununo, Anjeni, Andit Tid), structures must have a gradient and waterways to safely drain excess water. In particular, the waterways need to be grassed or in another way protected from incision and gully erosion.

Recommendations such as those mentioned above would give the extension service clues about which directions to take when seeking suitable SWC technologies. For the farmer, however, what counts is production, and for the subsistence farmer it is mainly the production of the current season that guarantees the mere survival of the family. As pointed out by Hurni (1988b), SWC is a reproductive process, which unfortunately involves short-term costs while benefits can only be expected in the long run. SWC has rarely been in the short-term interest of land users because it often shows a negative net present value (Kappel, 1996). This is due to the unfavorable time gap between paying the costs and earning the benefits. Belay (1992) reports for Gununo area that farmers would not even consider yield increase an acceptable compensation for losing productive land occupied by SWC structures.

The need to keep conservation costs low and to increase production calls for intensified production, supported for example by agronomic and vegetative SWC. Generally, soil cover is considered a highly efficient means of controlling erosion, at least as effective as the runoff barrier approach, but less costly (Young, 1989). However, one should not draw the conclusion that vegetative SWC can entirely replace structural SWC. SCRP research has shown that particularly during extreme rainfall periods that cause greater part of the annual soil loss plant cover may not provide sufficient protection (cf. Chapters 4 and 5). Similarly, runon from upslope areas often causes rill and gully erosion that may not be controlled by vegetative measures alone. Therefore, structural SWC is still an indispensable component of farm management, in particular to control drainage and erosion, both during times of low and high vegetation cover.

The considerable effect of the SWC measures tested in reducing soil loss should be taken as a point of departure. But it is essential to further develop suitable combinations of structural, agronomic, and vegetative SWC practices that can simultaneously raise production and protect the resources. At present, the greatest difficulty seems to be developing such solutions for sub-humid areas with secure high rainfall and climatic limitations on vegetative SWC (e.g. high altitudes with low temperature, or steep slopes with shallow soils).

Successful SWC is frequently connected with the following attributes: technical feasibility and adaptability, ecological soundness, economic viability, and social acceptance (Hagmann et al., 2002). To achieve a reasonable compromise among these attributes, experiments like the one discussed in this chapter can be considerably improved. The preparation of the experiment must become more important: negotiations with farmers as the implementers of SWC must reveal which measures to be tested. Ideally, farmers and researchers select the most promising indigenous – i.e. already accepted and integrated – technologies together, and improvements are negotiated on this basis. SWC measures need to be designed, monitored and assessed jointly so that they can be incrementally improved.

Many of the above conclusions, e.g. to make SWC more effective by increasing production and popular participation, are not new at all. For example, Hagmann (1996) provides an example from Zimbabwe indicating similar acceptance problems of SWC due to technical difficulties. Already in the 1980s, recommendations were made in Ethiopia to address land tenure issues, to develop a multi-sectoral strategy, or provide better infrastructure. Hurni (1993) developed several possible scenarios and options for the management of the land resource, stating that sustainable land management is more than mere technological development. There is a great demand for improvement of the socio-economic and political framework so that it enables farmers to use their land in a sustainable manner. Although these proposals are not new, improved socio-economic conditions are far from being achieved. Consequently, frequent failure of dominantly technical approaches can also be expected in the future (Nyssen et al., 2004b).

Assuming that all technologies listed above were already successfully implemented somewhere in the world, this does not automatically imply that they will also be useful when they are exported to other areas. Each implementation is accompanied by site-and user-specific limitations, which must be overcome to achieve efficient soil protection and sustainable land management. From a farmer's point of view, the decision on how to use the land and which crops to grow is not necessarily a deliberate haphazard act! Farmers' decisions strongly depend on the farm size, on the household income, assets and consumption pattern, on the family structure (producers and consumers), on the experience and knowledge, etc. (cf. Chapter 9). For an erosion and conservation expert, however, SWC is the prominent task of mandate to deliver services. For a farmer, by contrast, conservation is one task among many others, and often not the most urgent one. The central question from the farmer's point of view is how to cover the daily needs of food, energy and water, and whether SWC can play a significant part in it. This is so much important in areas where poverty keeps farmers from engaging in long-term investment on their land. In other words, farmers need to decide whether it is worthwhile to invest time, labor and other resources in SWC, or whether other e.g. social activities deserve more attention.

In order to make it more attractive particularly to small-scale farmers, SWC is regularly combined with incentives and subsidies (food for work, cash for work). One cannot say that this approach was generally a failure, because many impulses given through technical innovations would not have been possible without incentives. But the food for work approach cannot be called a success either. Its most important shortcomings are listed below (Fitsum and Holden, 2003; Bekelle and Holden, 1996; Nyssen et al., 2004a):

- The top-down approach, i.e. decisions on which technology to choose, where, when and how to implement, were usually made without consulting local stakeholders. Consequently, local knowledge that prevails in the community was altogether ignored or shallowly referred to.
- Uniform technologies and implementation modalities ignored biophysical, socio cultural and economic diversity.
- Traditionally, SWC was integrated into the farming system and benefited from synergies between different farming activities. After services and activities for undertaking SWC were paid separately (through Food for Work schemes) it became an isolated activity possibly performed for the sake of the one who pays, and thus introduced the dependency syndrome prevalent in many communities.
- The focus was laid on initial construction of structural SWC, while subsequent maintenance activities were considered a responsibility of the land users without taking due consideration if this was feasible at all and within the capacity of the farmers.
- Technologies chosen in such top-down manner and approach resulted in several technical shortcomings once they were implemented. Since the aim of such campaigns was “adoption” (acceptance of technologies one-to-one, as they were introduced), the potential of “adaptation” of the measures to the local situation was rarely taken into consideration. This again reinforced abandonment and neglect of, as well as loss of confidence on the farmers’ part in the introduction of further SWC.

8.5 A tool to assess effects and impacts of SWC

Generally, there is no shortage of well-described participatory tools of investigation, such as PRA, sample surveys, stakeholder analysis, social mapping, matrix / preference ranking, Venn diagrams, focus group discussions, key informant interviews, transect walks, wealth ranking, etc. But often neither time nor capital is available to run such studies, and practitioners have to rely on their own knowledge or on quick (and sometimes dirty) assessment methods. In general, an active inclusion of local stakeholders into the planning process and the involvement of local knowledge in SWC is absolutely essential to increase acceptance of measures and understanding of their functioning. Social networks can facilitate innovations; the development of knowledge and sharing of that knowledge can also increase social acceptability.

When talking about acceptability / acceptance, we do not refer to “adoption” of proposed standard SWC technologies but to constant “adaptation”, i.e. the continuous process of participatory technology development, a procedure of learning with phases of modification, assessment and improvement. The spider or amoeba diagram (Figure 8.8) is an instrument to visualize changes during such a process of learning. Preparation for the assessment involves selection of a meaningful set of indicators that can describe the “issue” under consideration at an early stage of cooperation (for more examples cf. Chapter 12 and the Annex). After selection the rating of each indicator needs to be agreed upon: what is considered the best, good, bad, very bad effect. Finally, measurements and observations will be carried out, and results will be interpreted. More information on the single steps can be found in Chapter 12. The selection and rating of indicators seems to be a domain of researchers who have to answer a specific research question. However, in a general development context it is very important that other stakeholders be involved in selecting and rating the indicators, because development and sustainability are normative issues that involve the personal judgment not only of researchers!

The example in Figure 8.8 is based on experimental plot data of Andit Tid, 1987, 3000 m a.s.l., on Eutric Regosol and 24 % slope. The year 1987 marks an early stage of terraces shortly after the construction of experimental plots. Taking the sustainability of SWC measure into consideration, always two indicators represent the ecological, economic and social dimensions of sustainability. While ecological and economic indicators were measured on plots (Table 8.9), the assessment of the social acceptability of SWC relies on informal discussions with farmers. The social indicator “compatibility with cultural values” (estimated percentage) mainly refers to religious restrictions for specific farming activities that may interfere with SWC activities. The social indicator “integrability into the farming system” (estimated percentage) is com-prised of conflicting issues mentioned by farmers, such as:

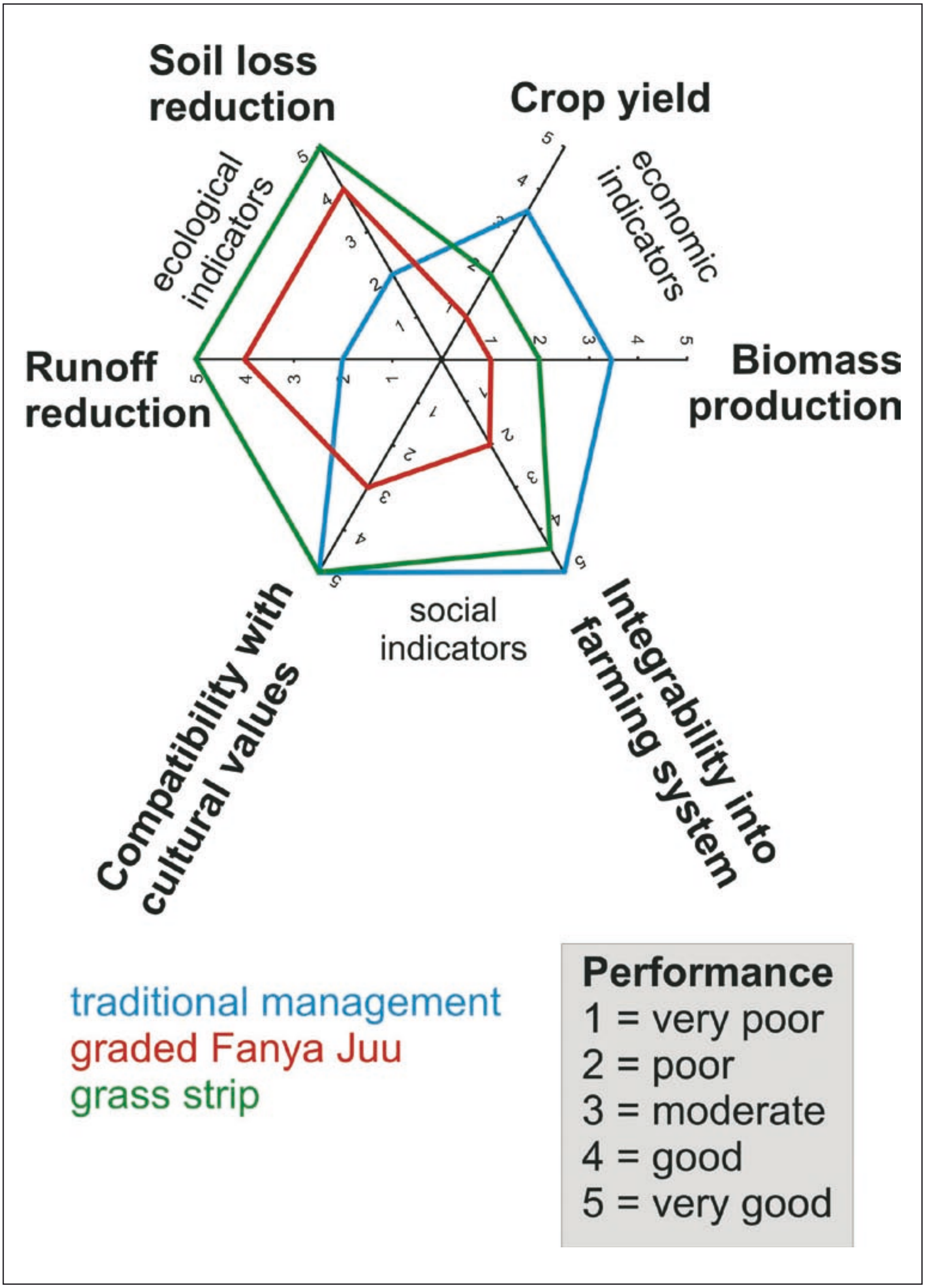


Figure 8.8: Assessing the performance of SWC measures (Drawing: Karl Herweg)

- rat / weed concentration in and around the terraces
- waterlogging above the SWC structures
- fertile soil misused as construction material
- narrow spacing conflicting with the ox-plow practice
- maintenance of terraces conflicting with open grazing practice
- permanent SWC conflicting with fragmentation and small size of farm plots
- terrace construction conflicting with other requirements of farm labor

Table 8.9: Rating of four measured indicators

Dimension	**Indicators**	**SWC measures**		
		traditional farming	**Fanya Juu**	**Grass strip**
Ecological	soil loss (t/ha)	42	15	4
	runoff (mm)	183	112	58
Economic	crop yield (barley, t/ha)	1.9	0.9	1.2
	biomass production (t/ha)	4.2	2.5	3.1

The rating of single indicators can first be expressed in the respective measurement units (t/ha, mm), but later harmonization of all scales and transformation into 5 classes without units is required. This is necessary for the sake of better communication. Farmers and researchers do have problems to understand each other's assessment, particularly if they use similar terms for different issues. Therefore, a number of different ratings are proposed here (Table 8.10). For example, the best possible achievement of each indicator – e.g. no soil loss – is given the rank "5". It could also be classified as 100% achievement of the optimum (e.g. 100% soil loss reduction), or be linked to the normative statement "very good". Similarly, an unsatisfactory achievement of each indicator is given the rank "1" – e.g. the highest erosion rate observed. It could also be classified as less than 20 % soil loss reduction, or be linked to the normative statement "very bad".

Table 8.10: Example of different ratings without using measurement units

Rank	**% Achievement of "optimum"**	**Judgment**
1	20%	very bad
2	40%	not satisfactory
3	60%	average
4	80%	good
5	100%	very good

The effects of three management and SWC practices (Figure 8.8) can be interpreted as follows:

- Naturally, the traditional management (= no SWC treatment) is 100% integrated into the farming system and 100% compatible with cultural values. Production of the concerned crop is not excellent but can be considered average in the area. The greatest deficits are high runoff and soil loss rates.
- The *Fanya Juu* effect represents a typical example of a “repair-shop mentality”. After assessing the traditional management, a focus was laid on improving the weak points only, in this case the ecological effects soil loss and runoff reduction. As a result, compared to the traditional practice, *Fanya Juu* was successful only in ecological terms, while the social and economic dimensions were neglected, which is indicated by rather poor viability and acceptability of *Fanya Juu*.
- The grass strip seems to be a better alternative, provided that production could be increased. Compared to the *Fanya Juu*, grass strip is less conflicting in social terms and not as effective in ecological terms. But with little improvement it has a good potential to receive desirable ratings in all indicators and dimensions.

The *Fanya Juu* example shows that it is dangerous to conclude from an assessment that only selected dimensions (indicators) with deficit effects deserve further attention. If the aim is to achieve a more sustainable SWC scheme, each measure must always be assessed holistically. This means that the effects in all dimensions must be observed simultaneously because they are inter-connected. For example, there is no acceptance without economic viability.

The number of indicators is certainly not restricted to six. There is also no obligation to have an equal number of indicators in each sustainability dimension, but it is essential not to ignore any dimension. The most important aspect is to select a meaningful set of indicators that can be communicated to the farmers, and that best represents the farm “reality”. As a rule it can be noted that:

- The lower the number of indicators, the clearer will be the resulting recommendation, but the more unrealistic it will be. For example, if we would assess different SWC measures using only one indicator – e.g. soil loss reduction – the one measure with the lowest soil loss could be clearly recommended. But using one indicator also means ignoring potential negative economic and social side effects, which disqualifies this seemingly clear recommendation as unrealistic.
- And vice versa, the higher the number of indicators, the more realistic is the assessment, but the more unclear could be the recommendation. For example, considering the six indicators used above, the assessment better reflects farmers’ reality, but it does not necessarily lead to a clear-cut recommendation. The result is likely to be a comparison that balances several positive and negative effects of different measures. This does not – and should not – provide an extension worker with a ready-made decision; it is only intended to help farmers decide what measures could be suitable in their situation.

8.6 Questions and issues for debate

- Figure 8.8 is based partly on measurements and partly on statements. The rating of each indicator includes personal judgment ("good", "bad"). What is your opinion, can a researcher who tries to be as objective as possible in his / her research tolerate personal judgment as integral part of such assessment? Why should he / she do that? How can we avoid that such assessment will be dominated by personal preferences of individual stakeholders?
- Even well intended interventions will always have negative side effects. To accept this and to monitor both positive and negative impacts is part of a process of learning and continuous adaptation of technologies to changing circumstances. But true learning requires transparency. For example, a subject matter specialist can never have the same deep insight as a local farmer and will consequently make mistakes when designing appropriate SWC. This brings the specialist into a dilemma. On the one hand, admitting mistakes and drawing the necessary conclusions would be an important part of the learning process, but he / she might also be blamed for making mistakes and face the consequences. On the other hand, if the specialist ignores own mistakes, the farmers will have to bear potential negative consequences. How would you handle this dilemma for yourself?

9 Sustainable Land Management as a New Approach

9.1 Attempts to describe sustainability

The definitions and thus also the concepts of what constitute sustainability – and likewise: sustainable development, sustainable land management, etc. – are plentiful (Greenland, 1994).

9.1.1 Definitions of sustainability (compiled by Greenland 1994)

1. The basic components are:
   - Sustainability as a long-term food sufficiency, which requires agricultural systems that are more ecologically based and that do not destroy their natural resources.
   - Sustainability as stewardship, that is, agricultural systems that are based on a conscious ethics regarding humankind's relationship to future generations and to other species.
   - Sustainability as community, that is, agricultural systems that are equitable. (Douglas, 1984)
2. The net productivity of biomass (positive mass balance per unit area per unit time) maintained over decades to centuries. (Conway, 1987)
3. It means survival. ("A CGIAR scientist", quoted by Walsh, 1991)
4. Low input, no input, organic farming. ("Some people", quoted by Plucknett, in Walsh, 1991)
5. Living on interest and not capital. ("Economists and Financial Analysts", quoted by Bennett, 1991)

9.1.2 Definitions of sustainable agricultural systems (compiled by Greenland 1994)

1. The successful management of resources for agriculture to satisfy changing human needs, while maintaining of enhancing the quality of the environment and conserving natural resources. (FAO, 1989)
2. (a) A system which maintains an acceptable and increasing level of productivity that satisfies prevailing needs and is continuously adapted to meet the future needs for increasing the carrying capacity of the resource base and other worthwhile human needs; or in other words,
   (b) A system in which the farmer continuously increases productivity at levels that are economically viable, ecologically sound, and culturally acceptable, through the efficient management of resources and orchestration of inputs in numbers, quanti-

ties, qualities, sequences and timing, with minimum damage to the environment and danger to human life. (Okigbo, 1991)
3. A system which involves the management and conservation of the natural resource base, and the orientation of technological and institutional changes in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development (in agriculture, forestry and fisheries sectors) conserves land, water, plant and animal genetic resources, and it is economically viable and socially acceptable. (FAO, 1991)
4. A cropping system is not sustainable unless the annual output shows a non-declining trend and is resistant, in terms of yield stability, to normal fluctuations of stress and disturbance. (Spencer and Swift, quoted by Swift et al., 1991)
5. A sustainable land management system is one that does not degrade the soil or significantly contaminate the environment, while providing necessary support to human life. (Greenland, 1994)

With regard to sustainable land management, it is important to define for what purpose the land is to be used. By far the greatest use is for agricultural, pastoral and forestry purposes although the functions of the soil are many (cf. Chapter 2).

Sustainable land management (SLM) can be defined as the use of land resources such as soils, water, animals and plants for the production of goods – to meet changing human needs – while assuring the long-term productive potential of these resources, and the maintenance of their environmental functions (Herweg et al., 1998).

In addition to the above-mentioned criteria, according to Hurni et al. (1996) SLM must include intra- and intergenerational equity. SLM is the foundation of sustainable agriculture, and a strategic component of sustainable development and poverty reduction (Hurni and Meyer, 2002; Wiesmann, 1998). In contrast to the situation just a few decades ago, there are currently only a few countries in the world that still have spare land resources to meet the needs of their expanding populations. In the majority of cases, production must be increased and intensified on land already under cultivation. Furthermore, in most developing countries, the majority of people are still engaged in primary agriculture, livestock production, forestry and fishery, and their livelihood and options for economic development are directly linked to the quality of the land and its resources.

Sustainable land management seeks to harmonize the often-conflicting objectives of intensified economic and social development, while maintaining and enhancing the ecological and global life support functions of land resources. Sustainable land management postulates that both these aims can be achieved simultaneously in a true win-win situation if things are done appropriately. In fact, practicing sustainable land management principles is one of the few options for land users to generate income without destroying the quality of the land as a basis for production.

Similar to the soil functions (cf. Chapter 2), land and its natural resources can also be looked at through its functions for society (Herweg et al., 1998):
Productive functions: to produce food, fodder, fuel, construction material, industrial goods, etc.
Physiological functions: to ensure human health by minimizing toxic substances in water, soils and plants, or hazards such as land slides, flash floods, etc.
Cultural functions: to preserve creation and the integrity of the landscape: the role(s) of water, land, forests and animals as an essential part of the cultural heritage, and to maintain the historical and aesthetic value of the landscape.
Ecological functions: to ensure maintenance of the ecosystem functions and global life support functions, including source / sink functions for greenhouse gases, filtering of water and pollutants, and maintenance of global geochemical (nutrient) cycles etc.

As indicated earlier, global definitions of "sustainability" remain somewhat general and vague. However, it is possible to develop a vision at the local land management level regarding what is more and what is less sustainable, compared to the years before. In this respect SLM is understood as an orientation where to move to, rather than a defined goal to reach. Since different actors have different views on sustainability, however, it will not be easy to develop a common vision, or, for example, to select indicators that doubtlessly proclaim more sustainable land management. In contrast to this, indicators or symptoms of unsustainable land management are easier to identify and agree to, such as soil degradation, water quality decline, loss of biodiversity, increased incidence of plant diseases, etc. Such symptoms are a result of inappropriate land management and exploitation of resources, the causes of which are often social, economical and political attributes rather than technical or agronomic considerations. Both sustainable and unsustainable land management can be approached through analyzing the options land users have to manage the land sustainably. Key questions are: Why do land users apply inappropriate management practices? Or what keeps them from applying more appropriate technologies? We may assume that land users are mostly aware of degradation but are not in a position to correct it, often due to political and economic circumstances, such as market price distortions, insecure land tenure, misuse of subsidies and incentives, etc. They mostly know that these factors limit their choice of options to practice sustainable land management.

When approaching SLM through symptoms of unsustainability, it needs to be kept in mind though, that the absence of unsustainability indicators alone (e.g. no signs of soil erosion) does not yet mean that the land management has become more sustainable. It seems important to have a vision of both, what is unsustainable (what to avoid) and what would be sustainable (where to go). This little discourse should have made it clear that "sustainability" is a normative concept based on people's perceptions and desires. Then what could be the contribution of research – that claims to be "free of value" – to sustainability?

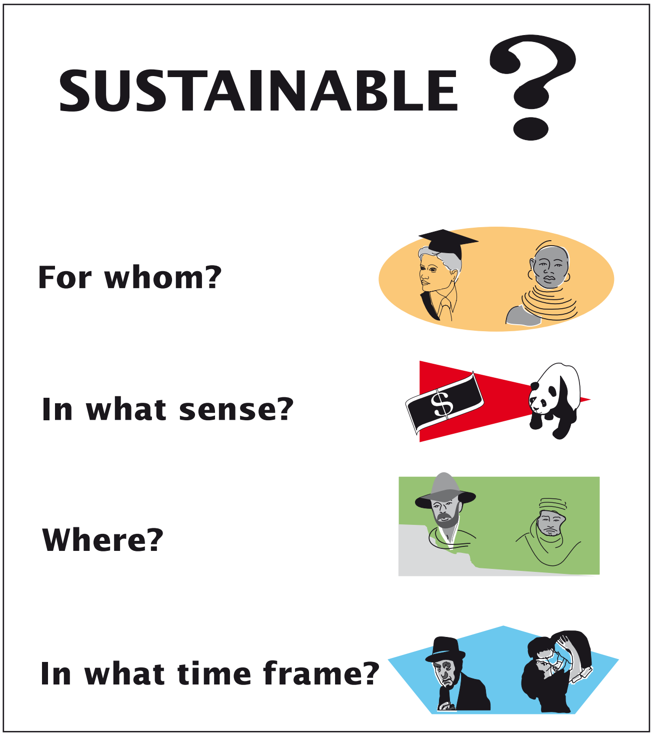


Figure 9.1 Sustainability – some critical questions instead of a definition (Drawing: Karl Herweg)

9.2 Approaching sustainability through unsustainability

There are certain basic limitations for SLM, such as strong humidity or aridity, that are difficult to overcome efficiently, and if at all, then only with intensive efforts. The following list of examples, although not complete, may provide a general idea that a comprehensive view and a basic understanding of the interrelatedness of factors is necessary to make land management in general and soil and water conservation in particular more sustainable.

Climate: attributes of climate such as extreme temperatures, high evaporation and variable precipitation limit plant growth and, at the same time, the potential of vegetative and agronomic soil and water conservation measures to protect the soil. Variable or erratic rainfall affects the chances to keep a reasonable balance between water retention and drainage by structural soil and water conservation interventions.

Soils: soils that are prone to water logging, with low rooting depth, also affect plant growth exhibiting either low water and nutrient storage capacity or nutrient leaching and toxicity. Moreover the external input required to potentially exploit such type of soils will be prohibitive for resource poor farmers.

Topography: steep slopes and slopes of irregular shape (concave, convex) are a strong challenge to structural soil and water conservation measures such as drainage systems and terraces.

Biotic factors: vegetative soil and water conservation is threatened by plants, which build up competition with crops for water, nutrient or light and those that harbor pests and diseases.

Land use: needs for food, fodder and other products determine the prevailing land use of a farm. Competing needs can hamper all kinds of efforts to protect soils and other natural resources. Land use changes become more unlikely, the more the land users depend on their own natural and human resources, and the fewer alternatives such as off farm income are offered. Greater production can be obtained by cultivating more land, by cultivating land using greater inputs, or by cultivating existing land more frequently. The question is whether we can continue to extend and intensify production sustainably. The reasons for the concern are the declining and stagnating yields per unit of input (and in some case per unit of land), the declining quantity and quality of land resources, declining soil nutrient reserves, and various forms of environmental degradation.

In Ethiopia the highlands have been inhabited for several centuries and agriculture constituted the main stay of the people. The farming practices and the population pressure resulted in massive soil erosion severely reducing the productive capacity of the land. Formerly, attempts in resettling the highland farmers across regions in areas better endowed with land resources in the lowlands were not successful for technical, political and socio-economic reasons. Realizing the fact that agriculture will for some time be the main occupation of the farming communities and taking into consideration the fact that recent resettlements (within regions) constitute a means of relieving the land from pressure, as a stakeholder in a process of designing a resettlement program, what would be the several considerations you need to make before embarking into such a scheme?

Economy: Soil and water conservation activities that provide short-term benefits have a high potential to be adapted, e.g. agroforestry in humid areas or water harvesting and conservation in arid and semi-arid areas. Farms that are small, far from a market, that have many very young or very old consumers have a limited range of technological options and may often not be in a position to afford expensive structural measures. The short perspective may often be an obstacle for long-term investments into effective soil and water conservation. Such arguments may alienate smallholders and poor farmers from policies and strategies that are aimed in obtaining short-term economic benefits. This again may lead into creating a disfranchised group of poor members of society that are not represented in the economic aspects of SLM. Hence a balance needs to be made between the economic gains and the environmental attributes of the interventions for enhancing SLM.

Socio-cultural settings: on the one hand, traditional norms and values are strong; on the other hand, policies, the economy, population and the environment are changing rapidly. As a consequence, traditional values and also technologies may no longer be as effective as they used to be. Innovative technologies and forward looking points of view might be necessary but always imply high economic risks, which may hamper soil and water conservation measures already from the beginning. The remedies offered by modern technology, involving a range of improved soil, water, and nutrient management methods may be capable of producing sufficient yields. What is less certain is whether their use is known in the area, whether the needed inputs are available, and whether their use is economic, etc. Finding ways to remedy the human problems of poverty must be a high priority in dealing with unsustainability. Socio-ecological systems are influenced by the day- to-day management decisions of large numbers of stakeholders (from the local to the global level). Each decision influences the interests of other stakeholders, both now and in the future (Campbell and Hagmann, 2003). Many of the institutions aimed at balancing different stakeholder interests are of limited effectiveness.

This implies that considerable analysis and intervention will have to be devoted to institutional and organizational issues, from village level institutions to international agreements (Hurni et. al., 2004; Knowler, 2004). This can be engaging for example in the Semien Mountains for sustainable land management where approaches in development required institutional and organizational aspects are important where common property and open access resources prevail, especially where these resources are valued differently at different scales. The Walya Ibex for example is globally endangered but can be considered a valueless species in the area because of the extreme poverty observed. For such type of situations the integrated development of the area will require the involvement of the whole spectrum of stakeholders at local, national and international levels (Hurni and Meyer, 2002; Hurni and Ludi, 2000) through a process of participatory learning and planning. The aim should be a win-win situation, where local people can share benefits resulting from the protection of the animals. However, even if resources are held privately, innovation (including technical) is a social and organizational process (Douthwaite, 2002; Hagmann et al., 2002) that needs to consider the decision of the members of the community on matters of common interest (Wiesmann, 1998).

Politics: ill-advised pricing and credit policies and land policies are driving the unsustainability cycle working against long-term investment. This is because pricing policies may change unpredictably, while international subsidized pricing undermines returns to local agriculture. Wrong land-use policies, including tenure and rights, provide incentives for unsustainable land management. Political bias and expediency, especially the under valuation of food, cause a net flow of resources out of rural area, which in turn leads to further rural impoverishment: Neglect of investment in rural sectors is accompanied by centralization of natural resource management and bureaucratic control of resources, which leads to non local development planning and a consequent reduction in local responsibility and incentives. Insufficient legislation or enforcement of land related laws and by-laws, as well as insecure land tenure systems play a prominent role in limiting efficient soil and water conservation activities. Decentralization on the other hand can be a better solution for local natural resources management. However, in the absence of local capacity and the tools to undertake the local planning process, decentralization may be an impediment to SLM and provide misguided opportunities for misusing land resources in unsustainable way for short-term benefits. Empowering the local actors apparently needs to be given prominence.

Education and infrastructure: another factor of importance for SLM is infrastructure, such as roads and markets to sell new products and to purchase relevant inputs for soil and water conservation. Access to education, training and agricultural extension is a precondition for technology development. Finally a disenfranchised rural population degrading and inappropriately using resources further reduces production potential and thus the ability to correct factors that lead to poverty. The poverty cycle deepens, leading to an increase in social instability, decreased investment and productivity, and further soil and water degradation.

Figure 9.2 is an example of approaching SLM through unsustainability. The caption provides a “guided tour”. The figure can be used as a checklist, e.g. to find the core issues of SLM relevant for the area and stakeholders you work in and with, to identify core issues, formulate hypotheses and select indicators for impact monitoring (cf. Chapter 12). Of course, the figure is not a “complete” representation of reality, but it is rather meant as a tool that needs to be continuously adapted (re-drawn), e.g. selecting the factors relevant in your area of work, supplemented by new factors that are not yet included.

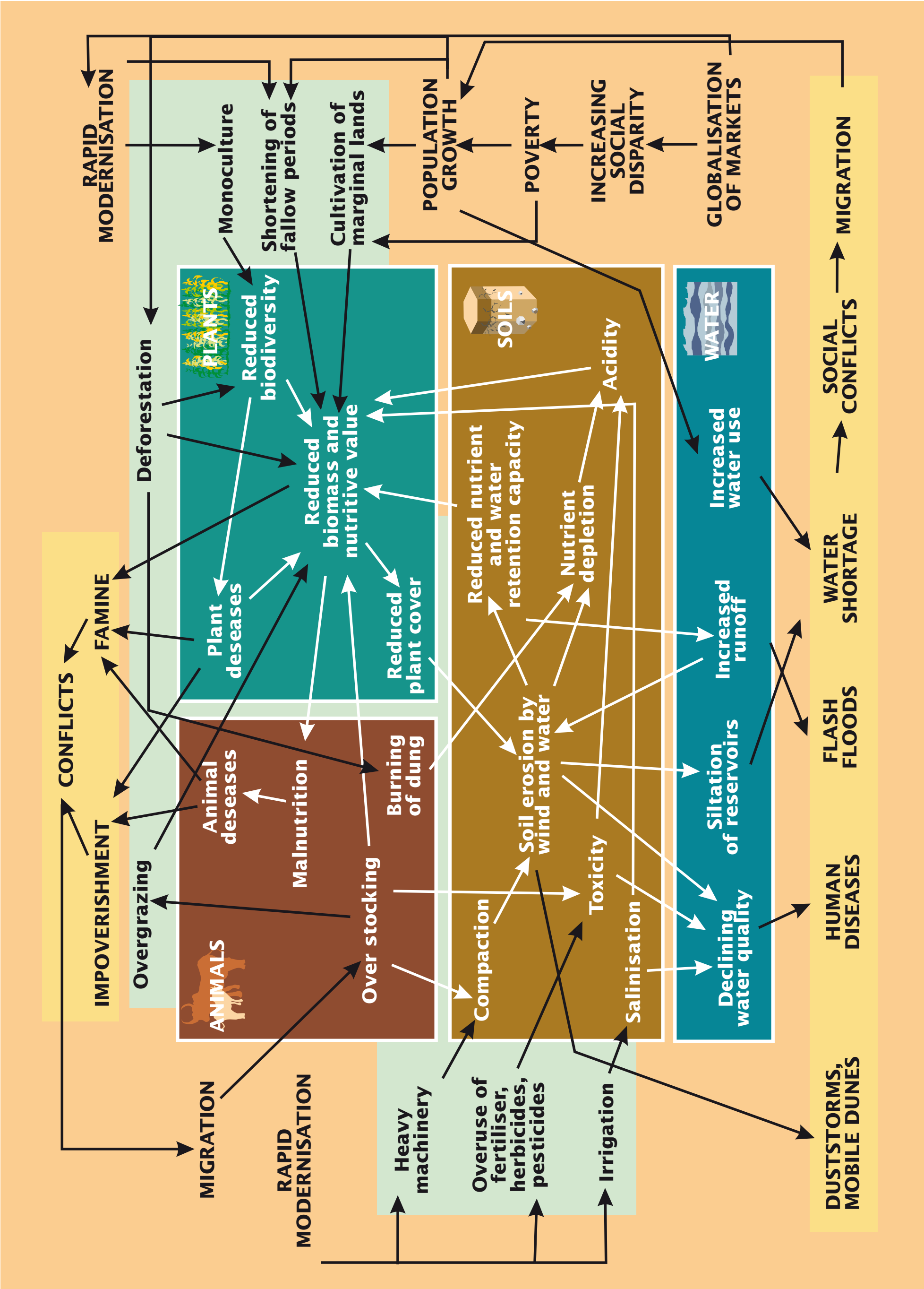


Figure 9.2: Approaching sustainability through unsustainability: society – land management – natural resources interrelations (Drawing: Karl Herweg)

There are basically two ways to begin work according to Figure 9.2. If you have a socio-economic background, you may prefer to begin with the identification of societal changes or problems along the margin (in the "background") of the diagram. If you have a bio-physical background, you may wish to start with the resource degradation symptoms in the centre ("front") of the diagram. Either way will eventually lead you to the inter-linkage of society, land management and land resources.

- *Along the margins of the diagram you will find societal problems (e.g. land insecurity, poverty, migration, etc.) that could be causes and/or effects of resource degradation. Identify the apparent societal problems in your area of work and define their relationship to land management problems (e.g. cultivation of marginal lands, deforestation, overgrazing, etc.) by following and adding arrows between the different components. You may also observe issues other than those included in the diagram. Add them and try to find their links with other components. Land management problems often result in resource degradation, the facets of which are indicated in the centre of the diagram.*
- *The centre of the diagram contains the four land resources: plants, animals, soils and water. Identify the symptoms of resource degradation prevailing in your area of work (e.g. reduced biodiversity, salinization, water quality decline, etc.). Follow the arrows forward and backward and notice how different symptoms are interlinked. In your area you may observe symptoms other than those included in the diagram. Add them and try to find their connections with other symptoms. These degradation processes may have different impacts on the society, examples of which are indicated by arrows leading from the centre to the margins of the diagram (e.g. water shortage, famine, etc.).*

Note that the society experiences the degradation of water, plant and animal resources directly. Degradation of the soil resources, by contrast, is mostly felt indirectly through its detrimental impacts on other resources. Therefore, soil degradation is often not or too late perceived as a problem, when the damage is already severe and corrections are costly!

9.3 Sustainability dimensions

Several proposals have been made to design more or less simple and practical ways to describe and come close to "sustainability" and sustainable land management (Figure 9.3). Any land use system is unsustainable if it leads to irreversible biophysical changes in the ability of the land to produce equally well in a future cycle of similar land use, or if the costs of reversing the changes are prohibitive. The most common categorization is describing sustainability as a function of three dimensions: ecological, economic and social, while the "social" dimension may as well include policy, institutional and cultural aspects. Thus, unsustainability may be either biophysical, social, economic or a combination of these factors – or dimensions – of sustainability.

Figure 9.3: The three dimensions of sustainability

Another approach known as ”the barometer of Sustainability (IUCN, 1997), that considers two important dimension, human well-being and ecosystem well-being. The World Bank developed another scheme known as the “five pillars of sustainability” (productivity, security, protection, viability, and acceptability), which has a stronger economic focus. Within a local context, sustainable land management combines policies, technologies and activities aimed at integrating socio-economic principles with environmental concerns (Dumanski, 1997) so as to simultaneously:

- Maintain or enhance production/services (**productivity**, indicator is e.g. crop yield)
- Reduce the level of production risk (**security**, indicators are e.g. soil cover, yield variability, climate)
- Protect natural resources and prevent their degradation (**protection**, indicators are e.g. soil quality and quantity, water quality and quantity, biodiversity)
- Be economically viable (**viability** is given e.g. if the contribution of the activity to income is sufficient to make its continuation attractive; indicators are e.g. net farm profitability, input use efficiency, off-farm income, return to labour)
- Be socially acceptable (**acceptability** is given e.g. if activities are negotiated among all stakeholders, when possible conflicts of interest are addressed and resolved, and when activities adequately meet the needs of poorer people; indicators are e.g. use of conservation practices, farm decision-making criteria).

To a certain extent, every categorization is deliberate, but it will serve the purpose as long as it makes sure that different dimensions are combined in one approach. These dimensions serve only one purpose, i.e. not to forget important aspects and details. The differentiation in three dimensions, **ecological, economic, and social** (socio-cultural) has been proven to be very practical, for example in selecting indicators for measurement, observation, monitoring and assessment, and will therefore be used in this document.

9.4 The need for a multi-level-multi-stakeholder approach

In general, biophysical limitations cause technical problems, which often can be addressed by technical solutions and which can be minimized through technology development. Socio-cultural, economic and political limitations, in contrast, provide the necessary – or insufficient – framework to make technologies work. These latter limitations can no longer be addressed at the farm or community level. This shows that soil and resource management involves stakeholders from nearly all parts of the society including those at the grass-roots, community, national and international levels (Hurni, 1989; Figure 9.4). According to Hurni and Meyer (2002) only such an integrated approach can lead to adequate solution pertaining to agreements, conventions, treaties on the environment and economic development that can be addressed at the international level. Land use plans, agricultural calendars and inter-household collaborations can be dealt with at the community and household levels considering the available social organization. Although extension systems are highly decentralized to cater for the services of the communities and households, market and infrastructure development is better reflected within the national and regional planning sphere.

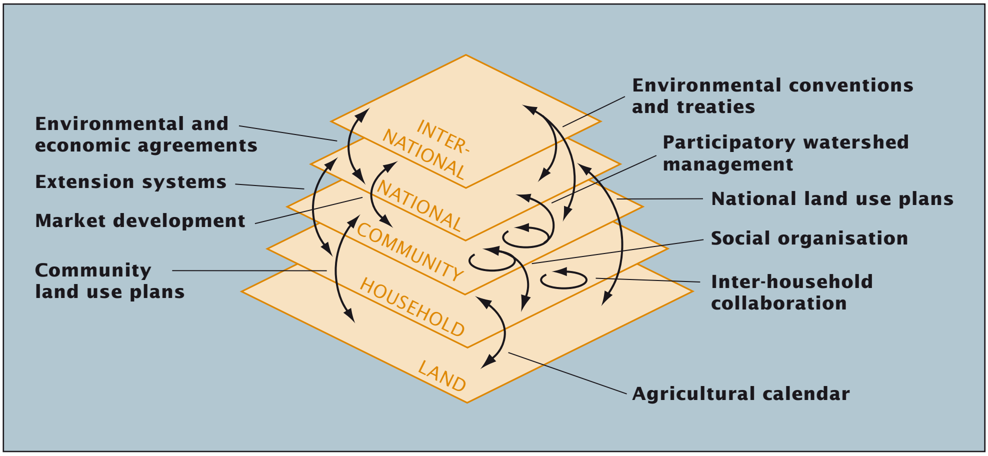


Figure 9.4: The multi-level-multi-stakeholder approach (Source: Hurni, 1989)

9.5 The role of science in SLM

It was stressed before that taking an SLM perspective means dealing with complex systems. Sayer and Campbell (2004) describe such complexity as:

- **Overlapping and competing stakeholder interests**, i.e. economic, social and political agendas of farmers, decision-makers, traders, etc.
- **Spatially and temporally variable resources**, such as soils, water and annual and perennial crops, etc.
- **High frequency of non-linearity, uncertainty, and time lags**; e.g. irregular price fluctuations, unpredictable conflicts, not-normally distributed and extreme soil erosion values, delayed enforcement of political decisions, etc.
- **High context or site specificity** indicating that e.g. technologies cannot be simply "extrapolated" to areas with different cultural, social, and economic patterns.

In view of these well known facts it is astonishing how development agencies, researchers, experts, decision-makers and others often propose or demand highly simplified "solutions" to meet peoples' needs, thus assuming a level of control and predictability that does not exist in real life. This leads us, among other things, also to the question what in particular should be the role of research in sustainable development, or, in this case, in sustainable land management. We will also have to argue whether "sustainability" itself is an appropriate goal research and development should address.

It will be difficult if not impossible for science to cope with the above-mentioned complexity as a whole and try to produce scientific evidence of all interrelations within such a system. According to Sayer and Campbell (2004), the best outcome of research in development is supporting and facilitating negotiation and learning processes among other stakeholders. Consequently, a research approach to development requires an interdisciplinary (cross disciplinary approach, CGIAR) and transdisciplinary approach, involving researchers of different disciplines and other stakeholders such as land users, politicians, etc. (Hurni and Wiesmann, 2002). Research has to accept that decisions concerning development – be it changing the economic and political framework or local level resource management practices – are made elsewhere, and that the decision-taking actors have their own experience and knowledge systems parallel to the scientific knowledge system. According to Sayer and Campbell (2004) such tacit knowledge systems (e.g. the indigenous knowledge system of farmers) is the key to dealing with complexity, because these systems are highly sophisticated and characterized by adaptive systems management. Sustainability is a normative concept based on different stakeholders' values and visions on how the future should be, and may be not so much on scientific facts. Then the question is how can science and research make a valuable contribution for better decision-making in development?

Sayer and Campbell (2004) recommend that science can be used to:
- Extend the array of options for local stakeholders (e.g. providing them with explicit scientific knowledge in an understandable form);
- Monitor the systems changes (providing results for the public);
- Providing feedback on further interventions from a scientific point of view; and
- Beyond that, leave the details (and decisions) in the hands of the resource managers!

The authors provide a number of hints for an outline of action research, such as:
- Develop and apply interdisciplinary and integrated modes of enquiry to understand and explain systems behavior instead of conducting several independent disciplinary studies. Study how to change, not what to change. Learn what to exclude in research.
- Establish long-term monitoring capacities – in particular in the South – to discover interactions between slow phenomena (e.g. climate change) and fast phenomena (e.g. flash floods). Study irregular patterns, not generic patterns.
- Work across scales (local, regional, national, etc.)
- When aiming at outputs, such as technologies, take their evolutionary and adaptive character, i.e. in particular the process of learning and innovation into account. Incorporate impact monitoring as a tool of learning.
- Link explicit (scientific) and tacit (indigenous) knowledge.
- Focus on adaptation (= change), not sustainability (= stagnation).

9.6 Developing an actor-oriented perspective

In most of the previous chapters we put a strong focus on the biophysical aspects of SLM. The following two models, describing the rational of land users in making decisions, provide good examples of what science can actually contribute to dealing with complexity. The search for an improved land management requires a better understanding of the interrelationships linking ecological, socio-cultural and economic dimensions. For example, the search for SWC technologies was regularly accompanied by disappointment when seemingly effective technologies created negative social and economic side effects. Too often, technology development was pushed by external forces (from a farmer's point of view external refers to "outsiders", such as foreigners, but also national experts and extension agents). At the same time, internal or indigenous knowledge and technologies (internal refers to the local community) of the land users who finally have to cope with new technologies were ignored. To a large extent the edict of "adoption" (one-to-one-copy) did not foresee mechanisms of "adaptation" (variation), i.e. it did not take into account that land users have enough know how and innovative potential to use recommendations in a flexible manner so that they better fit into their specific situation.

In this context it is worthwhile to remember that many donor agencies have placed “empowerment” very high on their agenda. This implies that the creative potential of people can and should be mobilized in development and must not be dominated by external “solutions”. This brings us back to the role of external persons, such as researchers and agricultural advisors. Are they not responsible for better understanding local peoples’ perceptions, existing livelihood strategies and rational of decision and action, before interfering with their livelihoods?

9.6.1 Peasant-oriented perspective

Wiesmann (1998) has developed a theoretical framework that helps interpret local mechanisms of decision and change. His application of the framework – or structural model – in rural Kenya provides an excellent starting point for better understanding how decisions are made and actions are taken by the peasantry. The model is basically suitable to be concretized in the Ethiopian highland context, which may lead to some modifications. In contrast to many other models, Wiesmann incorporates the central question of the “sense”. It means that not ecological and non-ecological conditions as such will force an actor to do what he/she does. Changes rather depend whether he/she perceives these conditions as potential or limitation. This model was designed:

- to obtain a problem-oriented understanding of the rural livelihood system;
- to formulate region-specific problems and research hypotheses; and vas an instrument and product of interdisciplinary debate.

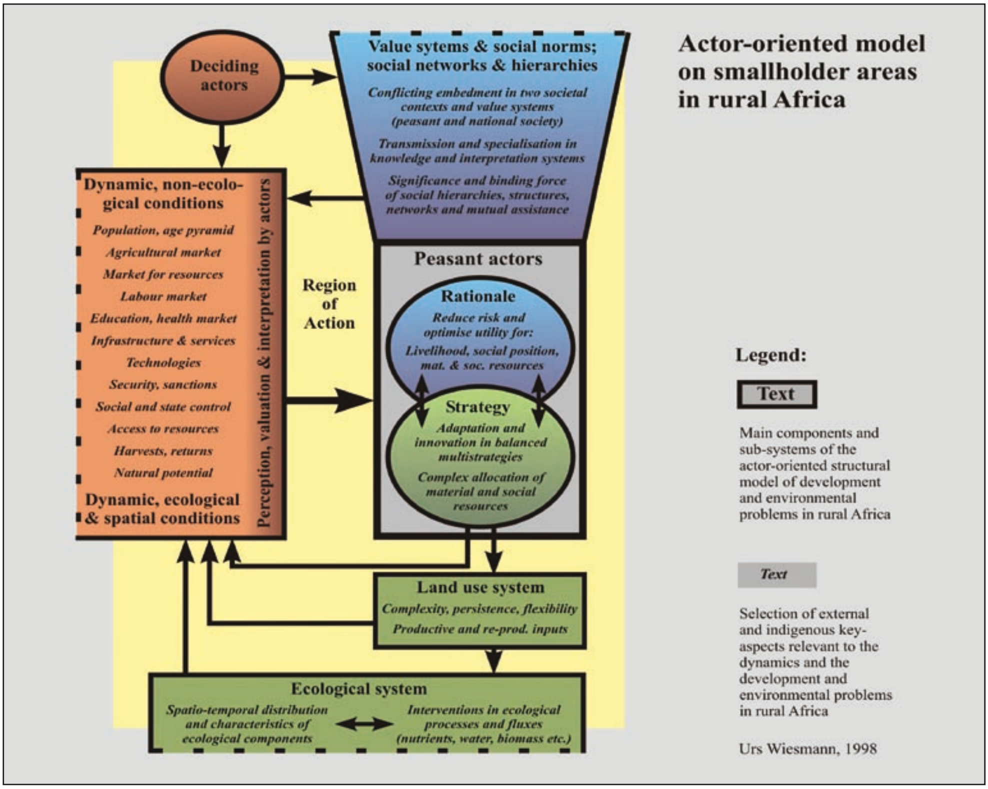


Figure 9.5: Peasant model (Source: Wiesmann, 1998)

In the centre of the model are smallholder actors (Wiesmann, 1998), who may be described as “peasants”. They are exposed to a dynamic environment characterized by different opposing forces:

- The framework of “meanings”, defined by the **value system & social norms, social networks and hierarchies**, their representations in social relationships, the forms of social organization, and their constituent logic; contradictions between traditional and national modern values may create tensions for an individual actor.
- **Dynamic** ecological, economic, social, cultural and political **conditions;** their influence on a person’s action depends very much on whether an actor perceives them as a potential or as a limitation.
- Peasants develop their **strategies of actions** within such setting of norms, values and dynamic conditions; multi-facetted strategies comprise a range of options, such as risk minimization as well as profit maximization where possible.

Based on the application of the model in rural Kenya, Wiesmann (1998) formulates three basic hypotheses:

- If changes in dynamic conditions are perceived as **periodic or stochastic fluctuations** (e.g. shortage of rainfall, price fluctuations, interventions by the government), the result may be a **non-reaction** of peasants. Such uncertainties are already inbuilt in their livelihood strategies (multi-strategies).
- If changes are perceived as **additional and reliable opportunities** (e.g. a new crop variety, reliable access to irrigation water) they may enhance rapid **adaptation and innovation**. For example, they have to fit into the existing multi-strategy or be compatible with the peasants' framework of meanings.
- If changes are perceived as **additional and persisting limitations** (e.g. declining soil fertility, reduction of pasture land) peasants will compensate losses in one field of action by strengthening other fields, instead of investing great efforts in reducing the limitation (e.g. establishing SWC schemes to combat severe degradation). Addressing the limitation directly will only be considered if this action promises additional opportunities or benefits.

9.6.2 Sustainable livelihoods approach

According to Chambers and Conway (1992) a "livelihood comprises the capabilities, assets and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets both now and in the future, while not undermining the natural resource base".

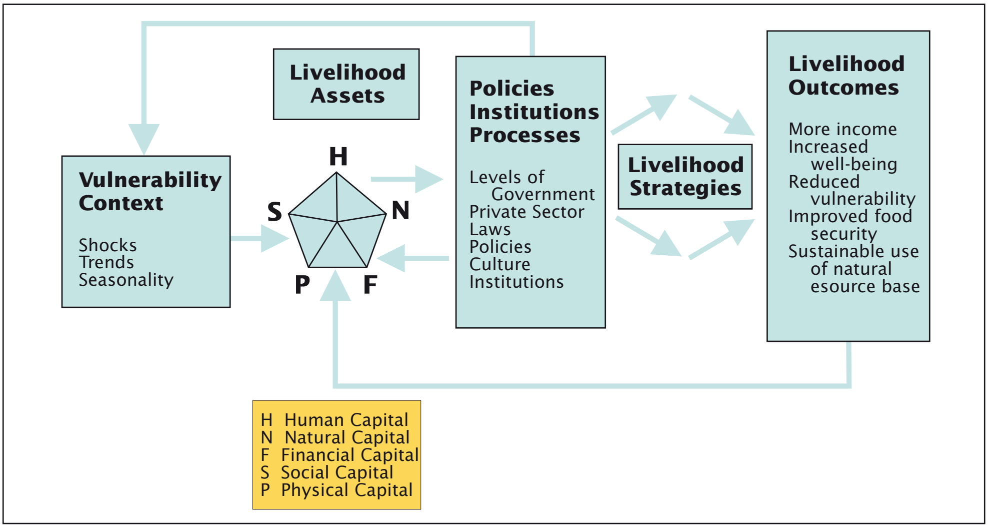


Figure 9.6: The sustainable livelihoods approach (Source: DFID, 2002)

Kollmair and Gamper (2002) describe the livelihood model as a tool developed to obtain a holistic view in understanding stakeholders' livelihood as a whole, with all its facets. Being aware that it is impossible to represent the entire complexity of reality, the model is intended to provide a manageable interpretation frame to identify the most pressing constraints people are facing. In a simplified way, the model assumes that stakeholders operate in a context of vulnerability, having access to various assets (human, natural, financial, social, and physical capital). These assets gain importance through the prevailing social, institutional and organizational context (transforming structures and processes) that influences the livelihood strategies chosen to reach self-defined livelihood outcomes (DFID, 1999).

Thus, the model provides a checklist of important issues of livelihood and their multiple interrelations and processes. It can be used for several purposes:
- to identify development options and their interference with the livelihoods of the poor;
- to describe the interrelationships between biophysical (ecological) and socio-economic dimensions of sustainability;
- to monitor impacts of development cooperation and increase project efficiency;
- to structure development research.

9.7 Questions and issues for debate:

- It should not be a problem for you to describe what “sustainable land management” means from your view as SWC “expert”. Try now to take different points of view: imagine you were a farmer / a farmer’s wife / a policy maker, how would they probably describe “sustainable land management” from their points of view?
- Interestingly, a holistic picture that includes interrelatedness is a typical criteria for indigenous knowledge systems. During your studies until now – we may call it the development of expert knowledge – you spent a lot of time on disintegrating a holistic view and focus on disciplinary strings of knowledge. It often requires special efforts to re-gain a holistic view. So do you think that your training was appropriate and will put you in a position to really assist the Ethiopian land users in their struggle for a more sustainable land management and livelihood?
- The concepts of sustainability and conservation contain connotations such as careful change, maintenance, preservation, etc., which may also be interpreted as stagnation. What do you think, in case of subsistence agriculture, for instance, wouldn’t moderate changes rather “freeze” a fairly unsatisfactory status quo for the smallholders, and would not a quicker change of the situation be desirable?
- We have indicated the need for a multi-level-multi-stakeholder approach. In practice, however, bringing different stakeholders – and power relations – together is not an easy task. Participation should not only be a catchword; we have to be clear that it is a time-consuming and potentially conflicting issue. Can you think of factors that may limit and those that enable sound participation in your area of work? Can you also think of measures to reduce limiting factors and enhance enabling factors?

10. Indigenous Knowledge as an Entry Point to Participatory Technology Development

10.1 What is indigenous knowledge? – A definition by the World Bank

The increasing attention indigenous knowledge is receiving by academia and the development institutions has not yet led to a unanimous perception of the concept of indigenous knowledge. The definitions are essentially not contradictory; they overlap in many aspects. As quoted by the World Bank (1997), Warren (1991) and Flavier (1995) present typical definitions by suggesting: *Indigenous knowledge (IK) is the local knowledge – knowledge that is unique to a given culture or society.* ***IK contrasts with the international knowledge system generated by universities, research institutions and private firms.*** *It is the basis for local-level decision making in agriculture, health care, food preparation, education, natural resources management, and a host of other activities in rural communities. It is the information base for a society, which facilitates communication and decision-making. Indigenous information systems are dynamic, and are continually influenced by internal creativity and experimentation as well as by contact with external systems.* According to Ellen and Harris (1996) there are distinct characteristics to understand and comprehend indigenous knowledge.

Why is indigenous knowledge important?

In the emerging global knowledge economy a country's ability to build and mobilize knowledge capital, is equally essential for sustainable land management as the availability of physical and financial capital (World Bank, 1997). The basic component of any country's knowledge system is its indigenous knowledge. It encompasses the skills, experiences and insights of people, applied to maintain or improve their livelihood.

Significant contribution to global knowledge have originated from indigenous people, for instance in human and veterinary medicine, with their intimate understanding of their environments, local people had developed knowledge systems that contributed to modern medicine and health care. Indigenous knowledge is developed and adapted continuously to gradually changing environments and passed down from generation to generation and closely interwoven with people's cultures and values. Indigenous knowledge is also the social capital of the poor, their main asset to invest in the struggle for survival, to produce food, to provide for shelter or to achieve control of their own lives.

Indigenous knowledge systems are at a risk of becoming extinct

Because of rapidly changing natural environments and fast pacing economic, political and cultural changes on a global scale, indigenous knowledge is at risk. Practices vanish, as they become inappropriate for new challenges or because they adapt too slowly. However, many practices disappear only because of the intrusion of foreign technologies or development concepts that promise short-term gains or solutions to problems without being capable of sustaining them. The tragedy of the impending disappearances of indigenous knowledge is most obvious to those who have developed it and make a living through it. But implications for others can be detrimental as well, when skills, technologies, artifacts, problem solving strategies and expertise are lost (Kibwana et al., 2001b).

Indigenous knowledge is part of the lives of the rural poor

The livelihood of the rural poor depends almost entirely on specific skills and knowledge essential for their survival. Accordingly for the development process, indigenous knowledge is of particular relevance for the following sectors and strategies:
- Agriculture
- Animal husbandry and ethno-veterinary medicine
- Use and management of natural resources
- Primary health care, preventive medicine and psychosocial care
- Savings and lending
- Education
- Community development
- Poverty alleviation through self-help and societal care

Indigenous knowledge is not fully utilized in the development process

Conventional approaches imply that development processes always require technology transfers from locations that are perceived as more advanced. This has often led to overlooking the potential of local experiences and practices. The following experience on sorghum improvement for alleviating food insecurity in the sorghum growing regions of Ethiopia is a typical example where the indigenous knowledge existing within the society is not captured in the development of the new varieties.

Example:
According to Oduol (1992) higher yielding sorghum varieties were introduced in Ethiopia to increase food security and income for farmers and rural communities. When weather and other conditions were favorable, the modern varieties proved a success. However, in some areas complete crop failures were observed, whereas

local varieties, with a higher variance of traits, were less susceptible to the frequent droughts. The loss of an entire crop was considered by the farming community as more than offset by the lower, average yields of the local varieties that performed better also under extreme conditions. An approach that had included the local experience of farmers might have resulted in a balanced mix of local and introduced varieties, to reduce the risk for the producers. Introduced varieties and commercially marketed seeds are replacing local varieties; along with them the concomitant local knowledge disappears. Efforts are being made to preserve genes and clones, however the seeds do not carry the instructions how to grow them. The knowledge needs to be captured, preserved and transferred as well. This is not realized in the collection schemes carried by several breeders and crop improvement experts thereby losing the knowledge system that had been preserved by the communities in their efforts to sustain these varieties of crops.

Indigenous knowledge is relevant on three levels for the development process

1. It is, obviously, most important for the local community, in which the bearers of such knowledge live and produce, to make a living under the given biophysical, social, economic and cultural conditions.
2. Development agents (Community Based Organizations (CBOs), Non Governmaental Organizations (NGOs), governments, donors, local leaders, and private sector initiatives) need to recognize it, value it and appreciate it in their interaction with the local communities. Before incorporating it in their approaches, they need to understand it and critically validate it against the usefulness for their intended objectives (Kibwana et al., 2001b).
3. Lastly, indigenous knowledge forms part of the global knowledge. In this context, it has a value and relevance in itself. Indigenous knowledge can be preserved, transferred, or adapted elsewhere.

The development process interacts with indigenous knowledge

Three scenarios can be observed when designing or implementing development programs or projects. A development strategy either:
1. relies entirely or substantially on indigenous knowledge,
2. overrides indigenous knowledge, or
3. incorporates indigenous knowledge.

Planners and implementers need to decide which path to follow. Rational conclusions are based on determining whether indigenous knowledge would contribute to solving existing problems and achieving the intended objectives. In most cases, a careful amalgamation of indigenous and external knowledge would be most promising, leaving the choice, the rate and degree of adoption and adaptation to the clients. External knowledge does not necessarily mean modern technology, it includes also indigenous practices developed and applied under similar conditions elsewhere. These techniques are then likely to be adapted faster and applied more successfully. To foster such a transfer, a sound understanding of indigenous knowledge is needed. This requires means for the capture and validation, as well as for the eventual exchange, transfer and dissemination of indigenous knowledge.

Source: http://www.worldbank.org/afr/ik/basic.htm

10.2. Indigenous soil and water conservation

Indigenous SWC is used to describe a practice or an idea which has either been generated locally or which has been introduced and then transformed and incorporated by the local people into their farming systems to improve their livelihood (UNDP/RELMA/Sida, 1999; Yohannes, 1998) (Figure 10.1).

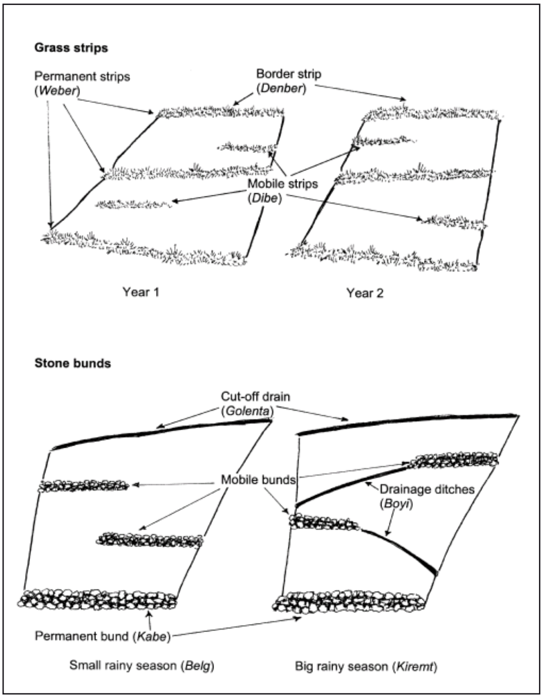


Figure 10.1: Flexible use of SWC

Farmers adopt and adapt SWC interventions to suit their land, e.g. selectively replacing permanent measures by temporary structures (Drawing: Karl Herweg)

In many publications the term "local" and "traditional" are used synonymously with "indigenous". Those who discover the new techniques (not inherited from family or imposed by extension system) are the innovator farmers who could be acting as groups or as individuals in a given community (Yohannes, 2001). Obviously and with less oversimplification of the issue, every farmer is to some degree an innovator considering the wide-ranging diversity of farm operational activities at plot level. In real time situation no two plots of land possessed by a farmer are treated identically by the same farmer, let alone by different farmers because not only of the needs and requirements of the diverse plots (physiochemical properties of the soils and land quality differences), but also the farming knowledge developed by the farmer for each specific plot (Yohannes and Herweg, 2000). This is why the SWC schemes imposed in the 1980s that could not consider such site specificities faced some problems of acceptance and adoption. Figure 10.2 indicates a history of technology development

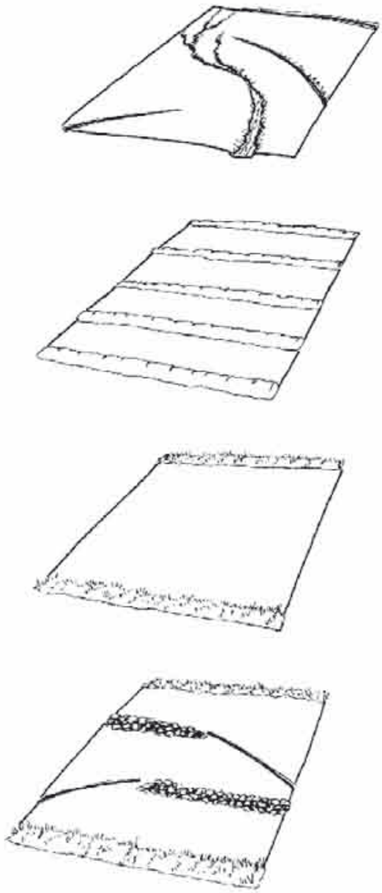


Figure 10.2 Adaptation of SWC structures (Drawing: Karl Herweg)

in the Ethiopian highlands. (1) Initially, experts observed soil erosion concluding that traditional SWC was not effective. This led them to design the imposed SWC schemes (2), which had one major purpose: soil conservation. After facing several negative side effects under these schemes, farmers first started to selectively remove structures (3) and finally integrated introduced measures with indigenous knowledge (4). The new scheme serves more than only for conservation. It may involve other functions as well, such as demarcating field borders, drain specific parts, enrich top soil at other parts, etc. Only the basic principles of a technology remained the same.

Photo 10.1: Selective removal of SWC structures – a first step to a new SWC system

This photo was taken 1993 in Andit Tid and shows the first phase of farmers' modification and adaptation of an imposed SWC scheme, mostly in order to create a greater area of production between two bunds. Most farmers seem to be very selective in which bunds they remove and which ones they keep, while a few farmers removed all soil bunds from their fields and others removed none. (Photo: Karl Herweg 1993)

Photo 10.2: Photo-monitoring: slope treated with SWC measures (Andit Tid 1988)
In the early 1980s, this slope was treated with soil and stone bunds and a waterway (Photo: Karl Herweg 1988).

Photo 10.3: Photo-monitoring: modified SWC measures (Andit Tid 1993)
In 1993 the farmer started to remove some of the SWC structures. Two "dark" rows indicate where the bunds were before. The relatively dark color is pointing at the fertile topsoil that was accumulated above the former terrace (Photo: Karl Herweg 1993).

The interest in indigenous practices had been developed with the orientation towards sustainable land management, when realizing that most external development interventions were not as successful as anticipated, while the wider local community continued to apply indigenous practices (Wogayehu and Drake 2002). Moreover, many organizations involved in rural development with focus in sustainable land management were found to be more successful by integrating indigenous practices than those who did not (Sonneveld and Keyzer, 2003; Sonnenveld, 2003, 2002; Waters-Bayer et al.,, 2001). Time and again it becomes very obvious that the deep rooted and untapped indigenous practices are a fundamental point of departure for the sustainable agricultural development. However, there is also differentiation between members of the community in their efforts to utilize indigenous soil and water conservation measures that needs to be addressed further.

Community differentiation in decision-making

The understanding of the different levels of decision-making in rural communities is very essential for the development of appropriate approaches and technologies for sustainable land management. For example, at macro level a given community can be differentiated in religion, ethnic composition and agro-climatic setting. At meso level farmers can differ in their skills, knowledge, experiences, family size, wealth assets (e.g. number of oxen is often mentioned by farmers as a major indicator to distinguish “rich” from “poor” farmers, because 2 oxen indicate independence for plowing), status and rank, gender and access to land and rights to resources use. At micro level the household can be differentiated by sex and age (Figures 10.3 and 10.4). Accordingly, problems, priorities and coping strategies can vary considerably between and within communities and even households (Million, 2001). Similarly the

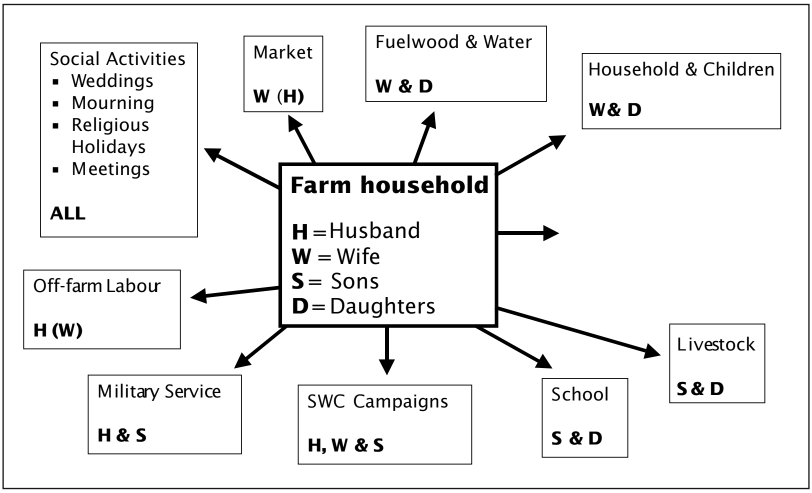


Figure 10.3: Labor division (Source: Karl Herweg)

community members make different levels of decisions in accordance to the attributes that make the differentiation. For example the community sets rules and regulations for the management and utilization of common resources like grassland, area closures and community plantations (Mitiku and Kindeya, 2002). On the other hand some decisions on adjacent plots (bund construction, diversion ditch construction, etc.) can be made under neighborhood level, while the individual household decides what should be done on its fragmented farm plots. Such differentiations are dynamic and subject to adjustments dependent on the level of consultations and participation achieved among the members of the community.

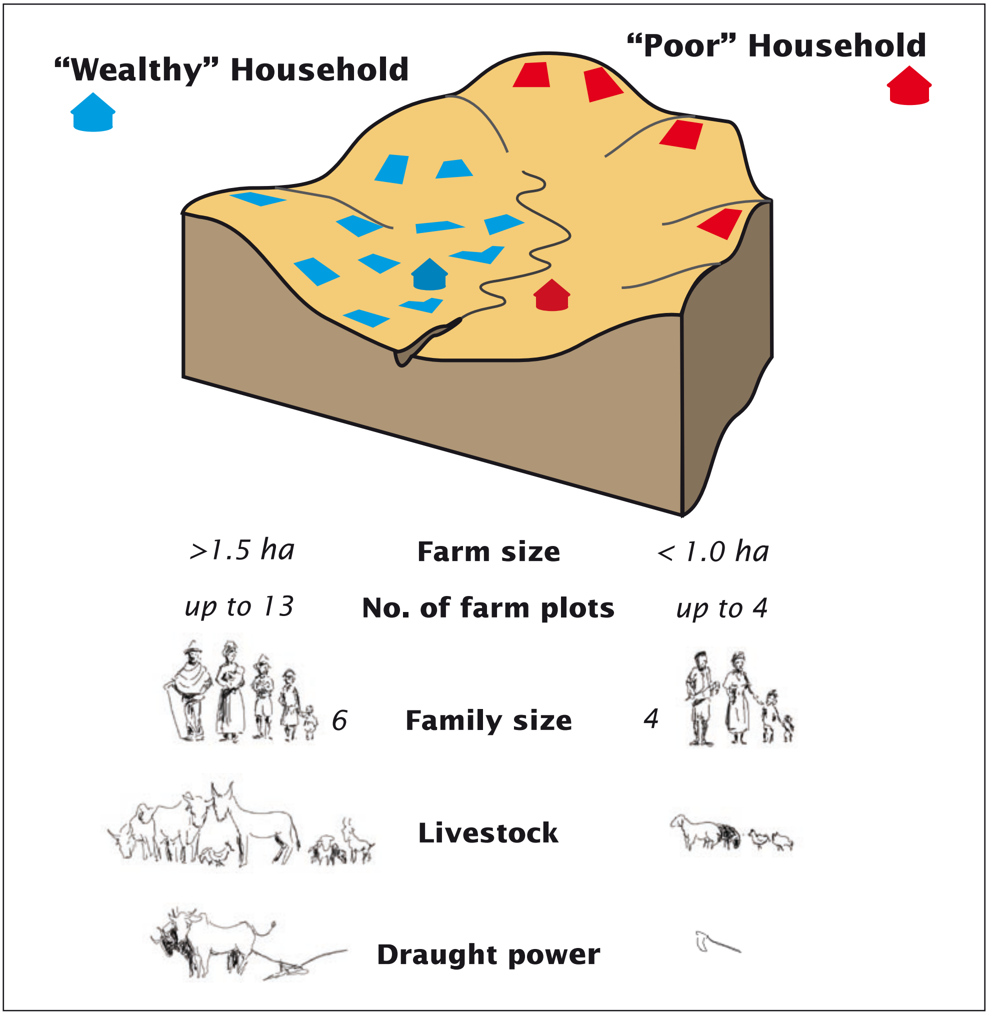


Figure 10.4: Wealth ranking

Extension cannot treat all farmers in the same way with the same package of recommendations. Farmers developed the criteria for wealth ranking themselves. (Drawing: Karl Herweg)

Common Indigenous SWC (ISWC) practices

- **Vegetative and agronomic practices,** such as contour plowing (retain water and reduce surface run-off), fallow (fertility improvement and source of fodder), crop rotation (fertility improvement and pest and disease control), manuring (soil fertility maintenance and the challenge of competition with fuel wood), mixed cropping, grass strips, trash lines (sorghum / maize straw and stubble)
- **Structural (mechanical, physical) practices,** such as permanent and temporal stone bunds (site specific), traditional ditches (ox plow), cut-off drains (ox plowing and human labor), check dams.

Managing marginal lands, for example, involves a sophisticated combination of measures. Shallow soils on steep slopes contain enough stones for stone mulching. Staggered stone bunds, and zero tillage or hoeing help controlling erosion. Controlled grazing and cultivation only during the short rainy season maintain a minimum soil cover. Planting fast growing crops reduces labor inputs for protecting fields that are far from the homesteads, from wildlife encroachment during night.

Characteristics of ISWC measures

The following major features characterize most of the indigenous SWC technologies:

- **Site specificity:** due to the heterogeneous nature of the farming plots (soil, micro-climate, slope, etc.) owned by an individual farmer, different technologies and techniques are applied in each locality.
- **Flexibility and dynamics:** in a single plot usually different supplementary technologies and techniques are applied (agronomic, vegetative and structural). The techniques are also changing with the seasonal rainfall pattern; they can be permanent and temporary.
- **Multi-functionality:** the measures applied are not only confined to SWC but also to different other functions. For example, structures can serve as a fence, can improve fertility by accumulation of top soil, safe drainage of excess water, etc.
- **Combining both short- and long-term benefits:** production and protection elements are systematically integrated. For example, “moving” bunds and permanent bunds constructed within a plot have a synergy effect: short-term increase of production and long-term soil protection.
- **Integration in to the farming practice:** ISWC technologies are integrated to the farming system, and thus do not face problems of viability and acceptability, as introduced practices. For example, traditional ditches and grass strips are constructed during plowing. The construction of traditional bunds is integrated in other farm activities, such as plowing and weeding, and does not cause tremendous extra costs.

- **Reduced risks:** consequently, ISWC as part of the regular farming operation using local tools and materials, implies a lower risk than introduced technologies.
- **Involvement of local institutions:** in most of the farming and conservation activities local institutions (self-help groups, neighborhood) are involved in both labor mobilization and application§ of rules and regulations.

Generally, the indigenous SWC technologies are coined to harmonize ecological benefits (minimizing soil loss and run-off), economic benefits (sustaining and increasing production), and social benefits (preventing out-migration and brain drain). Nevertheless, unequal distribution of indigenous knowledge within the community is one of the fundamental limitations of indigenous technicalities.

10.3 Case studies

10.3.1 Konso

Konso special Wereda is located in Southern Ethiopia about 300 km from the regional capital Awassa. It has usually less than 500 mm of annual rainfall, which is very erratic in distribution. The average land holding is less than one hectare and the average family size per household is about seven people. The major ISWC techniques practiced in Konso, according to Yohannes and Herweg (2000), are stone (back-slope) terraces. Because hand hoeing is widely practiced, the spacing between the stone terraces is narrower than in areas where ox plowing is practiced. In Konso, back slope terracing has been applied far from the homestead for many generations. In this mountainous region with a considerable population pressure, terrace construction is a prerequisite for bringing more land into cultivation. The technology is not self-standing; terracing is integrated with the use of micro-basins, trash-lines, mixed cropping and agroforestry.

- **Micro basins,** *kaha*, are constructed within the stone terraces during the land preparation activities, for the purpose of harvesting and concentrating water nearer to growing plants.
- **Trash-lines** are prepared at the ridges of the bunds and micro-basins, using the straw and stubble from maize and sorghum. They serve as mulch (to reduce the rain drop splash effect and minimize evaporation), and to improve soil fertility along the bunds and micro-basins through the eventual decomposition of the stubble.
- **Mixed cropping** involves growing different types of crops simultaneously, such as maize, sorghum, millet, wheat, barely, beans and sunflower as a component of land use intensification with no apparent spatial arrangement. The seeding rate depends on the level of soil moisture, which is assessed by the farmers. If the farmers assume that moisture is sufficient, more seeds are planted than under dryer

conditions. Selective thinning is practiced during periods of moisture stress within the growing period. The thinned plants and weeds serve as fodder for livestock.

- **Agro-forestry,** perennial plants such as coffee, chat and multi-purpose trees such as *moringa* are planted at the foot of the bunds.

10.3.2 Irob: dams to trap silt and water

The practice of trapping silt and harvesting water in narrow valley bottoms is developed by the Irob people in northern Tigray, on the border with Eritrea. Irob is a land of depths and heights, of droughts and floods, of frost and scorching sun. The altitude varies from 900 to 3200 m a.s.l, however most people live in areas situated between 1500 and 2700 m. Rainfall in the mainly habited area is low (200-600 mm annually) and highly variable in space and time. The Irob used to be a pastoral people, moving with their goats and cattle from the mountains on the eastern escarpment of the Ethiopian highlands to the lower plains. It was not until two or three generations ago that the Irob began to give attention to crop production (Mengistu, 2002), because they could no longer obtain enough cereals in exchange to their livestock products.

The landscape is mountainous, rugged and stony, with steep slopes and deep narrow valleys curved out the plateau by flush floods making the land less suitable for cultivating crops. In response to the ruggedness and the need for reclaiming land for crop cultivation, the Irob developed specific and site-appropriate methods of land management to capture soil and water. They build a series of checkdams in the seasonal watercourses and raised and lengthened the walls every year. Through this process of building, they have created step-like terraces that are now about 8 m wide and up to 10 m high, with about 20 m in between dams. This innovation is locally known as *daldal* and requires year-round effort over many years or even decades (Hagos and Asfeha, 1997).

The innovative *daldal* technique is a best practice because it is an indigenous land management scheme that has been recognized by many Irob people and by others living under similar harsh conditions as a way of creating land to produce food and obtain a supply of clean water (Asfaha and Waters-Bayer, 2001). The practice is sustainable in environmental terms, as it reduces soil erosion and makes use of soil and water that would otherwise have flowed into barren depressions and been wasted. Family members maintain it independently, but when the *daldal* becomes bigger and larger community groups take the task of maintaining the common resources (Waters-Bayer and Mengistu, 2002).

10.4 Ethnoecology and ethnopedology

The study of local environmental knowledge, ethnoecology, is increasingly seen as a key to both the conservation of agro- and biodiversity, and the increased effectiveness of sustainable land use (Kindeya et al.,, 2005; Mitiku et al.,, 2001; Berkes et al., 2000; Berkes, 1999; Nazarea, 1999; Havercort and Millar, 1994; Gadgil et al.,1993). Ethnopedology, also known as the study of local or indigenous soil knowledge and management, is a sub-component of ethnoecology that focuses on soil and land management by autochthonous populations (WinklerPrins and Barrera-Bassols, 2004). Local management of the soil resources can be critical to maintaining or enabling sustainable land management systems, especially in ecologically fragile areas of the world (WinklerPrins and Sandor, 2003).

Central to the ethnoecological theoretical framework developed by Toledo (2002, 2000, 1992a) is the kosmos-corpus-praxis triad. Kosmos is the belief system or cosmovision of a local people; corpus is the repertory of knowledge or cognitive systems; and praxis is the set of practical operations of that knowledge system. Together, this complex offers an integrative approach to the study of the processes of human appropriation of nature (Toledo, 2002). Ethnopedology concerns itself with local perceptions, knowledge, and management of the soil / land component of the environment (WinklerPrins and Barrera-Bassols, 2004). According to Barrera-Bassols and Zinck (2000), ethnopedology is defined as a “hybrid discipline structured from the combination of natural and social sciences, such as soil science and geopedological survey, social anthropology, rural geography, agronomy, and agroecology (Figure 10.5).

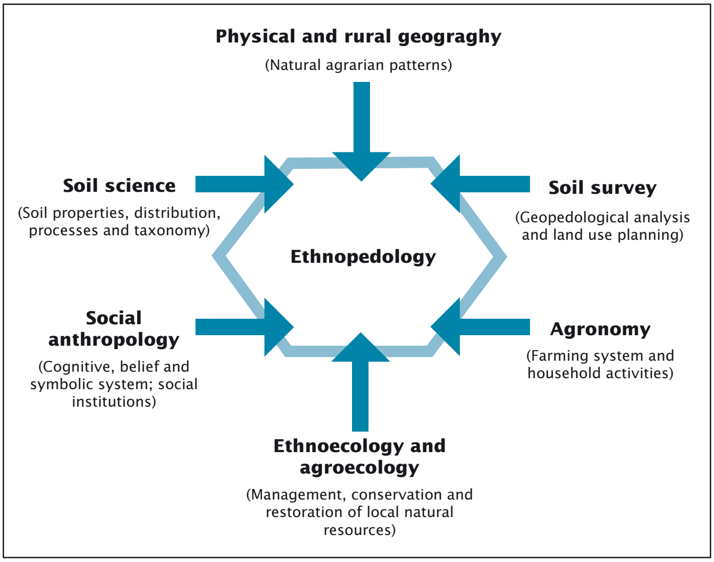


Figure 10.5. Ethnopedology as hybrid discipline (Sorce: Barrera-Bassols and Zinck, 2000)

Ethnopedology is, therefore, the local knowledge and understanding of soil morphology, genesis, and / or a local system of soil classification (Tabor, 1990). It encompasses local knowledge and management of landscape processes such as erosion and sedimentation. These landscape processes frequently include soil-building activities that improve the quality of the soil. Activities such as the build-up and maintenance of terraces and raised fields are obvious human manipulations of the soil landscape that demand an intimate and elaborate knowledge of the land. In the extension approaches in Ethiopia there is invariably references to soil types in the transfer of land-based technologies. However neither the scientific classification nor the traditional classification is used (Mitiku and Kindeya, 2002; Corbeels et al., 2000; Kelsa, 1999; Mitiku et al., 1999). References are made to the colors of the soils when recommendations are given for example on fertilization programs adopted by government extension packages. This has resulted not only in a blanket application of the fertilizers but also in confusing farmers in terms of comprehending the recommended rates because different colors can mean different attributes to the physiochemical differences of the same colored soils (Mitiku Haile, 1995).

Example:
Farmers in different parts of the country apply local knowledge, identify soil types and classify their soils by describing underlying differentiating characterstics (Mitiku et al., 1995; Teklu and Gezahegn, 2003; Yohannes and Herweg, 2000). Farmers tend to use top soil color, soil depth, soil texture (being clay or sand textured), water infiltration and percolation (considering water movement in the soil), suitability for irrigation (salinity, crusting, and compaction), capacity to retain heat, and response to the application of fertilizers and manure. In broad terms, farmers use the black and red colors to describe soils but distinctions are made between black soils that are soft and hard, in order to distinguish black heavy soils referred to as Vertisols (Kooticha, Walka, Mererre, Koreta Bita) from those relatively low in bulk density called Mollisols (Gombere, Biyyoo Gurraacha).
In Tigray farmers classify the land, hence the soil, in terms of three depth categories irrespective of soil color. Soils that are deeper than 150 cm are designated Reguid, those between 75 to 150 cm are called Maekelay, and shallower depths are referred to as Rekik (Mitiku and Kindeya, 2002; Corbeels et al., 2000). Further elaboration is made on the texture and the depth by considering deeper soils to be either Walka (clay soils) or Hutsa (sandy soils). The concept of water infiltration and percolation is embedded in the naming of the soil as Wiha geb by some farmers in parts of the Amhara region, to indicate easy movement of water into the soil and retention of water in the soil, which describes the texture of the soil in terms of being high or low in clay content as determined by stickiness to the fingers. This is also used to describe the position of the land in the landscape. Soils in the valley bottoms are considered to be high in moisture content as opposed to soils on sloppy areas that are affected by erosion resulting in sandy and coarse fragments.

From the above categories of criteria for indigenous nomenclature of the soils we can deduce that the local communities are using two dimensions.

10.4.1 The physical dimension of ethnopedology

Many soil properties referred to in indigenous soil nomenclature are visible to the eyes. The most important of those is soil color. In all the cases studied in Ethiopia, soil color takes prominence. Farmers would tend to classify their soils in terms of color in the first instance. The people of Mursi would classify their soil colors in accordance to the suitability of the color to paint their hair and body. Their classification takes a range of colors including red, brown, black and white. The color of the soils is related to the fertility status of the land. Dark colored soils are considered fertile, while reddish and gray soils are categorized as soils losing their fertility and poor soils that are highly degraded. Touching the soils and feeling with the fingers is used to assess the texture of the soils. Particular reference is also made to the temperature of soils during irrigation. If irrigation is prolonged in the season making it impossible to plow the land towards the end of June, farmers in Tigray would opt to fallow the irrigated land rather than putting it on crops because they notice the land that should have been dry and well aerated before the onset of the rainy season is still moist. In some areas tasting the soil is used to designate soils that are affected by salt. In the drier areas of Oromia the word Bole is used to designate areas of high salt content frequented by cattle and small ruminants as salt leaks. In Gelemso (Western Hararghe) farmers use Bole soil to settle sediments from turbid water as a means of purifying drinking water. In some parts of the highlands of central and northern Ethiopia, pregnant women also chew a lump of black and sticky soil. Although explanations are not given to this phenomenon, this shows that local knowledge in identifying and classifying the soils is embedded in the society.

10.4.2 The perceptual dimension of ethnopedology

Criteria for the perceptual dimension basically include any feature other than physical characteristics of the soil and reflect importance of local environment, distinctions and priorities. For example, farmers would designate their fertile soils to crops of importance not only for securing household livelihood but also that can fetch cash income. In the highlands of Ethiopia, where the black soils dominate, the land is used to produce tef which is both for household consumption, for cash income, and for the production of durum wheat solely for household consumption. In the coffee growing areas well drained red soils are used for coffee growing rather than the valley bottom soils, which are waterlogged and either used to produce maize or taro and yam (boyena), owing to the physical limitations of the soils. *Biyyoo Diimaa* in western Wollega and *Zouo Bitaa* in Wolayta are the red soils with low organic matter content, low fertility and in extreme cases the sub-soil exposed due to erosion and intensive tillage with out fallowing. They commonly occur on steep slopes. In low external input management they are only used for the cultivation of oil crops (*Gouizotia abyssinica* and *Linum ustitatissimum*). If the farmer is endowed with higher inputs these classes of soils are used for the production of tef, wheat and maize.

Several studies indicated that local classification systems have not only contributed towards to the understanding of the soils, but are being used to transfer land-based technologies to the farmers by the extension agents (Mitiku et al., 2001). However, further soil surveys and characterization of the major soils is essential to understand the dynamics of changes in the soil system for better and sustainable use of the land resources (Mesfin, 1998; WRB, 1998).

One encouraging trend over the past years is that the number of agricultural researchers and extentionists recognizing the value of indigenous knowledge has increased (EARO, 2002). Although the potential of indigenous knowledge systems is not to be over romanticized, they contain a wealth of local ecological knowledge and are at the same time the key to understanding the socio-cultural context of rural producers, thus representing a way to address problems that have plagued agricultural development programs for a long time. A balance should be made between what constitutes long-term research in soil and water conservation and the immediate needs of the farmers in solving their problems of increasing productivity and improved livelihood (Figure10.6).

Figure 10.6: A flood of specialists – advising or confusing farmers? (Drawing: Karl Herweg)

However, in the case of soil science and ethnopedology, could formal and indigenous knowledge be linked to improve the success of cooperation in sustainable land management development? Taxonomic and indigenous soil classifications vary greatly in their purpose and scale. Often the technical classifications produced during soil surveys are meaningless to the local people if their knowledge is not included in the interpretation of the resultant land evaluations (WinklerPrins, 1999; Ettema, 1994). If the resulting soil maps ever reach the farmers, they are usually on a scale not relevant to small farmers and advises about suitability of a soil for a specific crop are often not of interest to farmers who want to grow multiple crops. If soil surveys would start with indigenous classification, research and development efforts would gain time and insight, and communication between farmers, extension agents and researchers will be greatly enhanced if local soil nomenclature is included as part of the technical reports produced. This will ensure the spatial perception of the community members during the process of drawing household based land use plans.

10.5 Questions and issues for debate

- In the Rural Development Strategy of Ethiopia it is indicated that development strides be started by having “one leg on the ground”. What does this imply in terms of using indigenous knowledge as a tool for enhanced development?
- Farmers in central highlands of Ethiopia have developed system of classifying their lands and thereby their soils in accordance to suitability for less important crops if the land (soil) is thought to be exhausted and infertile. Is this also reflected in your area? If so can you enumerate some of these crops and the land units they are ascribed to?
- Referring to Figure 10.2: The process to come from (1), approximately 1980, to (4), 1995, took about 15 years, starting from local SWC with severe erosion damage via an total area coverage of imposed SWC measures, a removal of some of them, finally to an integrated system of introduced and indigenous components. Don’t you think that this process should have been more efficient and should have taken less time? Or do you think it needed 15 years to finally integrate the knowledge systems? Substantiate your arguments.
- Despite the wealth of indigenous knowledge, the problem of soil erosion could not be sufficiently controlled. Why not? What roles should indigenous (internal) and expert (external) knowledge play in the future?

11. Participatory Technology Development

11.1 Historical development

Today most natural resources scientists are acknowledged as specialists for whom it is legitimate to know progressively more and more about less and less. They are so much specialized that participation in research towards technology development is considered as fringing on the independence of the specific discipline.

Participatory research, or participatory action research as it is sometimes described, emerged from the work of academics and activists concerned about power relations related to knowledge creation, poverty and class. The approach evolved from international efforts that are often traced to researchers and educators in Tanzania during the early 1970s working to involve community people in research explicitly as partners and decision makers (Miller et al., 2005; Kibwana et al., 2001a). Together they investigated and analyzed social problems such as health care, each tapping their own sources of knowledge and experience to create more accurate, collective understanding of issues so that more effective actions could be taken in response. Participatory research takes different forms but usually brings people together with outside researchers and development activists to study issues of common concern and share control over the process of inquiry and action. Like action research, participatory research rejects the positivist notion of one "truth" that should be proven by deductive reasoning and evidence, recognizing instead that knowledge and reality are often socially constructed on the basis of deeply embedded values and worldviews. In contrast to mainstream action research, however, participatory research is explicitly intended to promote more equitable relations of power, and hence is not neutral. For both reasons, participatory research is open to challenges by traditional researchers and development practitioners. Aimed at transforming structures of injustice, it is based on a collective analysis and creation of knowledge that produces new awareness, critical thinking and more effective strategies of social change (Kibwana et al., 2001b).

Participatory Technology Development (PTD) is a wide term that refers to collaboration between farmers, development agents and researchers in a manner that combines the knowledge and skills of these various actors. Historically, farmers have developed their own deep-rooted research methodologies to cope with the changing environment. The indigenous technologies are the results of this process. Similarly farmers were also cooperating with researchers in the process of technology transfer, since farmers are the custodians of knowledge and practices that researchers base on to develop resources management technologies (Ouedraogo and Sawadogo, 2005). The conventional concept of soil and water conservation extension is that the role of the researcher is to identify and analyze the land users' problems. Solutions should then be developed on research stations and transferred to the farmers via the extension service. In this way, the extension service forms the link between the researcher and the farmer and helps the farmer put the new technologies into practice. Implementation was usually supported with incentives in cash or kind.

This approach to the transfer of technologies clearly separates the actors (researcher, extension agent and the land user) and puts them into a rigid straightjacket hierarchy in the processes of technology development and dissemination. An interesting case in the Ethiopian system of technology development and transfer scenario is the always-lamented notion of the absence of technology dissemination institutional set-up (EARO, 2002). Information flows only to one direction (from researcher to extension agent to farmer), making it exceptionally difficult to obtain feedbacks because such relationships also lack the capacity for monitoring and evaluation of the impacts of the transferred technology.

Researchers tend to work in isolation and extension agents seldom have a good working understanding of the farmers' environment and constraints to changing conditions. Often the extension is fragmented into separate specializations and, consequently, each specialization only depicts a narrow section of the overall situation. Moreover, different specializations may be attached to different institutions, with little or no interaction. With this approach, new technologies often address the symptoms, neglecting the underlying causes and farmers' constraints. Solutions, which may appear to be technically correct, may not be acceptable to the farmers. The concept is faulty in that it does not permit the free exchange of ideas and experiences between all the stakeholders involved in soil and water conservation.

If the concept becomes people-centred, traditional vertical hierarchies are minimized if not eliminated. Information flow is free and poly-directional. Farmers become equal partners, empowered and have the opportunity to participate in technology development, from the problem identification to implementation. Consequently, they are considered not only recipients but also expected to play a part in initiating and evaluating technology development. Farmers do not subdivide or segment their farming activities as researchers traditionally do. The whole farm enterprise dictates their thinking. Linkages within the farming system are understood. This wealth of traditional knowledge can then be used in the development and implementation of technologies. An outcome of this concept is that farmers recognize the limitations to their knowledge and traditional technologies to sustain production as pressure on the land increases. Present conditions dictate for participatory technology development, with a changed and closer relationship between the traditional institutions of research, extension and farming.

In the “participatory” on-farm research that had been propagated in the farming systems approach, farmer’s role was defined only to approve the delivered technologies by providing their land or service (contractual and consultative) without much involvement in either data collection or interpretation of the research results. However, through repeated failures to bring impact on such approach to research, gradually some weight has been given to indigenous practices and the role of farmers in decision-making. The researchers also played a role in the development of partnership research and the facilitation (collaborative and collegial) of participation of the farmers. In other words it was a step towards participatory technology development (PTD). It emerged out of many efforts to develop more sustainable agricultural systems mainly in the 1980s (Berhane and Mitiku, 2001; Yohannes and Herweg, 2000). Throughout this period the whole process of sustainability and farmer’s participation became a fundamental issue. Working towards sustainability requires understanding of local dynamics, problems and opportunities, development of specific solutions and empowerment of local organizations since farmers have also an intimate knowledge of these essential components (Wiesmann, 1998).

The PTD approach places people at the centre of development and works to support people’s efforts to achieve their own livelihood goals. At a practical level, the approach can help to address some of the questions on soil and water conservation interventions.

1. How does investment in soil and water conservation contribute to sustainable livelihoods, both in the short and long term? What benefits does it bring (e.g. productivity versus risk reduction)? What triggers the initiation or cessation of activities? What minimum levels of assets or wealth accumulation are necessary to support investment in soil and water technologies? Are there policy premises that support or undermine these activities?
2. When do households choose to invest and can they afford to?
3. What are alternative ways (opportunities) to achieve the same outcomes?
4. What is the opportunity cost of investing in soil and water conservation?

According to Fitsum and Holden (2003), Ludi (2004), Arega and Hassan (2003), Tesfaye (2003), Bekele and Holden (1996), and Anderson and Thampapillai (1990), level of income, access to low cost credit, labor availability, low discount rates, high levels of education among farmers, access to sound technical advise and secure land tenure are positively associated with the adoption of soil and water conservation interventions.

The government and NGOs in Ethiopia have currently used different participatory methodologies. These methods include Rapid Rural Appraisal (RRA), Participatory Rural Appraisal (PRA), Rapid Assessment of Agricultural Knowledge Systems (RAAKS), Local Level Participatory Planning Approach (LLPPA), Participatory Demonstration, Extension and Training systems (PADETS). Yet, these approaches are by and large characterized by incentives (cash and food for work) and campaign works with transfer of technologies as a driving force. No doubt, very few NGOs have made some attempt to PTD approaches (Yohannes, 2001). Today PTD application in agriculture and natural resource management is given due recognition. The active and joint involvement of the triple allies – farmers, extension workers and researchers – in a decentralized governance system can make the approach attractive and more promising for sustainable land management.

Underlining much of the research and extension work undertaken by soil and water conservation experts is the mistaken notion that farmers know little or nothing about soil conservation and therefore have to be shown on how to practice it. This neglect to the conservation effectiveness of farmers` own land management practices can lead to the imposition of unnecessary and often inappropriate solutions even under a decentralized decision making system for sound land use planning if the capacity and the tools to undertake such an exercise are not in place as shown by Fikru et al., (2005) in their studies at a Wereda level in Tigray. Chambers and Conway (1992) Critchely (1999), Yohannes and Herweg (2000), and Reij et al., (1992) have shown that farmers often have a good understanding of what is required for sustainable land management, and given the chance, they can develop their own innovative, and location-specific, good land management practices. It is therefore important that the specialists open their eyes, and observe what it is that farmers are already doing that confirms to the requirement of sustainable land management, and that they recognize the value of the indigenous expertise and local knowledge, and adapt their own expert advise accordingly (Liniger et al., 2004). However it should be also underlined that the indigenous knowledge is not sufficient enough to be the only panacea to solve the issues of SLM. What is being emphasized is that the researchers who are striving to develop new technologies need to consider the socio-economic conditions of the farming communities and base their new technologies on the existing knowledge of the beneficiaries. Further more the researchers need to put in place long-term monitoring and impact assessment indicators in place (cf. Chapter 12) as part of their efforts to develop new technologies.

The central point of PTD is farmer-led experimentation to find better ways of using available resources to improve the wellbeing of family and community members. The purpose of supporting farmer experimentation is to strengthen farmer's capacities to seek for and try out new ideas, so that they are better able to experiment and to adjust to changing conditions (Ouedraogo and Sawadogo, 2005). The purpose is not to convince farmers to adopt a new technology, but rather to encourage them to test new possibilities, choose what is right for their conditions or adapt the new ideas to their conditions (Van Veldhuizen et al., 2000; Veldhuizen, 1998). Generally PTD is an approach, which involves farmers in developing agricultural technologies that are appropriate to their particular situation.

11.2 Principles of PTD

- Participatory Rapid Appraisal (PRA) is an integral part of PTD. This needs to be seen from the point of view of having long-term research undertakings and the requirement for short-term outputs from research to mitigate constraints of unsustainability. Diagnosing a situation can be a short-term springboard for devising solutions but need not replace the long-term perspective for monitoring impacts of the technologies developed in a participatory approach.
- PTD is a sustaining learning process (learning by doing from real life experience). In this process what is gained in one aspect of the technology could be a failure for other aspect thereby necessitating changes in the approach to incorporate what is gained and learn from the failures.
- It is based on indigenous knowledge and practices as a point of departure. The available knowledge base within the communities is taken as a starting point (entry point) but not as a goal by itself. The spin-offs from research and development studies, notwithstanding their appropriateness, can form an integral part for further enhancing the technology development process.
- It takes local farmer innovators as a starting point. This aspect of PTD is crucial in view of identifying the entry points. Innovative farmers within farming communities can provide insights into what is going on within their context of technology development. How are they identified? What is their power base within the society? Are they innovative enough to improve their livelihoods or are they try it all individuals that look for incentives? It may be hard to come along to find such innovative farmers but with pertinent effort it is possible to identify them and make them partners in the development of the technologies based on their experiences.
- Different perspectives from individuals and groups are accommodated for wider application. Through the stakeholder analysis exercise, it becomes imperative that individuals and groups would like to be heard and involve in the process of technology development. The views of the different stakeholders needs to be integrated within the process to have it more grounding and benchmarking for further elaboration, enhancement and eventual monitoring.
- It is built on a process of discussions, communications and conflict resolution. In such a process it is permissible that difference in point of views might surface and could result in conflict of interests. There should be mechanisms in-built within the process to communicate such differences and put forward proposals on how to resolve the arising conflicts. Bylaws, traditional or otherwise need to be designed on how to address such issues within the community and beyond.
- It develops on the principles of partnerships between farmers, researchers and extension workers. The partnership is based on mutual respect and trust to facilitate the development, transfer, adoption and adaptation of the technologies designed and implemented jointly. An array of technologies can be developed through the partnership of the actors but the farmers need to be empowered to select those

technologies, which they regard as benefiting them both in the short and long-term perspectives.
- It is based on the linkage between indigenous knowledge and formal science, bridging the gaps of the conventional mono-disciplinary into transdisciplinary approaches. It may be hard for some disciplines to accept such simplifications but if changes are to be brought by communities in SLM, all relevant disciplines need to work together with farmers.
- It focuses on capacity building rather than a specific technical output, so that knowledge and skills are retained at both the local and higher levels. Methodologies and tools used should be sufficiently understood by the partners to enable them for scaling-up the outputs. If methods and tools are sophisticated to be only understood by the researchers only, sustaining the technologies will be undermined right from the beginning.
- Sustainability is the main focus in problem solving, building on what is achieved and value-adding to new ideas and innovations.
- It is a slow learning process that requires perseverance and reflections from all stakeholders involved. At every stage of the process feedback is essential to take corrective measures in time.
- PTD reinforces the existing creativity and experimental capacity of farmers.
- It builds human capacity for self-reliance.
- It helps empower land users in decision-making through partnership and accountability. All the partners in this process adhere to the principle of accountability in case of failures and successes. Backstopping and support for successful implementation should be provided unhindered.
- Farmers are not expected to approve and apply pre-designed trials but participate proactively on all aspects of the decisions that affect their livelihoods.
- Help farmers to respond to changing conditions.

11.3 Major clusters or phases of PTD activities

The PTD approach is not a panacea to the complex agricultural problems faced by the rural communities (Yohannes and Herweg, 2000). It has its potentials and limitations, which means that it needs to be gradually improved. According to VanVeldhuizen et al. (2000), a close look into the many good examples of interaction between farmers and 'outsiders' reveals a common pattern, which consists of six main clusters of activities.
- **Getting started:** Establishing contact between the farmers and 'outsiders' and agreeing on taking this approach to improved land management. This should be expressed at the outset. Understanding of the socio- cultural, economic and biophysical situation of the community will be facilitated with modalities of building trust

and confidence among partners. The need for openness need not be emphasized. It is how to ensure that trust and confidence is built that needs to be rectified.

- **Understand problems and opportunities:** Shared insights in to local agricultural potential and constraints and address the felt needs and priorities of the community. Synthesize the constraints for developing new ideas and insights to the development of technologies to mitigate the constraints.
- **Looking for things to try:** Selection of best bet indigenous practices and other possibly relevant technologies.
- **Experimentation:** Improvement of the capacity and skills of farmers in experimentation. Awareness creation and training of the partner farmers needs to be undertaken all along the process. Description of methods and tools for use in the experimentation can be easily understood by the farmers if done in simple terms.
- **Sharing the results:** Stimulate farmers based extension and diffusion of ideas and technologies. Ways and means of disseminating the results need to e incorporated in the process. Responsibilities of each partner are defined in accordance to the means to be employed.
- **Sustaining the PTD process:** Institutionalization of the approach in the routine work. Once the process is undertaken as either a pilot project or a program of development, institutionalizing the whole process within the institutions of the partners is important consideration if long lasting attributes are to be put in place.

11.3.1 Favorable conditions for PTD

- Flexibility in development and extension programs. If the extension system is rigid with several strings attached to it, PTD will face immense challenges. Access to partners and working with partners in a mutually agreed interventions focusing on improving the livelihood of the farmers is central to making the process flexible.
- Decentralizations of decision-making in planning. This might be simplistic in approach but is the most difficult part during implementation. There should be the capacity and the tools for planning at the lower level. If decisions are negatively influenced from above, decentralization becomes a process rather than an out put oriented goal.
- Regular evaluation of activities and impacts. From benchmarking the changes to monitoring the impacts within a time and space framework is essential. Consequently, scaling-up opportunities can be tapped into the system.
- Systematic staff development. At every stage of the process, those involved in the exercise are able to learn and build capacity for furthering PTD.
- Discovering new technical options. Farmers eventually will have menus of options to select and use them based on the resource endowment at their disposal.
- Storage and use of information. Elaborated databases can be established for further reference, impact monitoring and evaluation. Such data, however should also

consider ease of access not only by the researchers but also to all stakeholders involved in SLM.
- Allocation of resources (training and field operation, considering unforeseen risks). Although PTD could be easier to plan and implement, it entails costs. These costs have to be borne by the stakeholders.
- Building external relations. Partners in this process will benefit from the experiences of similar undertakings. Exchange visits enhance such relations.

11.3.2 Challenges and limitations

- **Long-term commitment:** Limited organizational support for long-term process by NGOs. Short-term benefits are sought rather than long lasting perspectives. Farmers planning horizons are diverse. Partners will be challenged with respect to such diversity of views. Prevailing on the perspectives of the farmers is difficult but should be accepted.
- **Sustaining the process:** Ensuring the continuity of the positive changes initiated with outside facilitation by the community and relevant government institutions.
- **Biased towards farmer innovators:** The experimentation is mainly initiated with agricultural innovation with farmer innovators, which may underestimate community wide problem analysis. Careful and persistent involvement of all members of the community is essential to avoid the danger of working with only the ”enlightened” ones.
- **Equity issue:** Innovator farmers alone do not necessarily represent the socio-economic and gender issues. All members of the community are stakeholders. They need to be heard and their views taken into consideration.
- **Innovation versus standards:** PTD encourages farmers to innovate, but researchers and extension workers find it challenging to share their standard findings to a wider community. This in a way hinders scaling-up. Attempts can be made through the process to standardize the available technologies in accordance to the specific situations of the communities involved.
- **Establishment of linkages:** Coordination of the stakeholders mainly from research and extension in the joint experimentation is a very difficult task, as everybody is preoccupied with own routine activities.
- **Harmonization of views:** Challenges to bring the different views of the farmers (socio-cultural dimensions) and western biased scientific analysis from extension and research. Dialogues, discussions and exchange of diverse views pertain possibilities to narrow the differences in approaches.

11.4 From participatory to transdisciplinary research

In their search for solutions to concrete societal problems, professional development organizations have as a rule been using participatory methods for more than two decades, as this approach has proved very effective (Hurni and Wiesmann, 2002). This means that both the local population and decision-makers are involved in planning and implementing projects. Participatory approaches were also taken up at a corresponding early stage in the so-called action research, although with considerably hesitation than in development cooperation. These largely empirical approaches were given theoretical basis only with the establishment of transdisciplinarity as a concept and approach. In essence, a transdisciplinary approach requires that phenomena under investigation be regarded from a perspective that (a) goes beyond specific disciplines and (b) is based on broad participation, characterized by systematic cooperation with those concerned (Hurni and Wiesmann, 2002).

Thus two issues need to be addressed in transdisciplinary research. First, do participatory research approaches adequately meet the requirements of transdisciplinarity, and do they need to be elaborated? Of course this means identifying the limits of transdisciplinarity, and also defining how and where there is an additional need for interdisciplinary and disciplinary methods. Second, the past few years have shown that transdisciplinary research is not only a meaningful addition to individually pursued research in the context of development cooperation, but that it also expands the potential of traditional methods in all other areas of research.

11.5 Questions and issues for debate

- Some people consider PTD a regression into backward thinking of technology development and adoption. Comment on these premises?
- Can you differentiate between transdisciplinary, crossdisciplinary, interdisciplinary, multidisciplinary and no disciplinary approaches to development and transfer of technology?
- Can you cite an example of a technology developed in a participatory approach from your area?
- What would be the enabling environment for participatory technology development in your field of study?
- A transdisciplinary approach requires that actors representing local knowledge systems have more influence on defining the (research) problem that should be solved (e.g. soil erosion, production), and which measures they are going to implement (e.g. vegetative SWC). This has consequences for research and extension. What changes must a researcher / extensionist envisage on a personal level (attitude, behavior), and what institutional changes (of universities, research institutions, extension service) do you think are essential, in order to better integrate indigenous knowledge in solving societal problems?

12. Impact Monitoring and Assessment

Recognizing the important role of indigenous "internal" knowledge in SLM requires simultaneously reviewing the roles of "external" stakeholders such as extension workers, experts (both foreign and national), researchers, etc. As mentioned already in Chapter 9, Sayer and Campbell (2004) recommend to "leave the details of land management in the hands of the resource managers" and emphasize at the same time that one of the major roles that outsiders can play is to monitor the systems changes. Parallel to this, there is an on-going discussion among international cooperation agencies and their partners about how to monitor systems changes with the intention to determine the impacts of development cooperation. To what extent do development projects and programs achieve their purposes and reach their goals? Are we doing things right (efficiency) and are we doing the right things (effectiveness)?

A contribution to this discussion is the participatory methodology of Impact Monitoring and Assessment (IMA) described by Herweg and Steiner (2002). The IMA methodology is a product of an international group of experts from various donor agencies (Herweg et al., 1998) who have designed and applied these monitoring and assessment procedures. Focusing on SLM, IMA provides numerous instruments for predicting, monitoring and assessing positive and negative outcomes (effects) and impacts. It is important to notice that, in contrast to common ex-post impact studies, which are carried out, *after* a project is finished, the six steps of IMA provide the user with tools of prediction and learning to improve **on-going** projects and programs.

12.1 Clarification of terminology

The terminology used in IMA relates to existing project cycle management procedures. It is important to note that the term "impact" covers quite a wide range of implications, which can be looked at as an impact chain of overlapping and interrelated links (Figure 12.1). Most development projects stop monitoring with the achievement of outputs (performance monitoring). IMA, by contrast, moves further by basically asking the questions "what are the consequences of these outputs, what will happen next, will they be utilized, will people find them useful, etc."?

The starting points of an impact chain are the **outputs** (results) that are planned and achieved by a project. A typical output of a SWC project would be "SWC technologies implemented in the project area". But the best technology is useless if it is not applied. So a first indication that an output may create further impacts is its **utilization**, e.g. the application (scaling-up) of a new SWC technology to a wider area. Only through utilization of the technology the users will be able to define the **usefulness** of the output, which includes both benefits and drawbacks. For example, due to a new SWC scheme crop yield may increase or decrease. It is important to keep in mind that, if interventions use incentives such as food-for-work to enhance broader application of a technology; utilization alone may not be an appropriate indication of a positive change. Only the usefulness as it is rated e.g. by local stakeholders may reveal a realistic picture. Together, utilization and usefulness are referred to as the **outcomes** (effects, direct impacts) of an intervention. Outcomes imply a process of learning, i.e. people may change their perceptions, attitudes and intentions, and this is the key to triggering further (indirect) **impacts**. For example, increased crop yield certainly indicates a positive outcome, but the products must be marketable to increase the household income. An increased household income may lead to more sustainable land management if part of it will be reinvested in the farm. But it may also lead to social conflicts, e.g. if it is spent for alcohol and other unwanted consumption.

This example of an impact chain is not comprehensive but shows that, at any point of the chain, there could be both positive and negative effects and impacts. Only a long-term monitoring will finally reveal whether or not the outcomes and impacts relate to more sustainable development, as it is often described by the overall goals of a project or program. For example, if local people learn how to adapt and integrate new technologies and make their land management both productive and protective, and if this helps them gain self-confidence and further explore their own creative potential, it would be a significant contribution to different development goals such as empowerment, poverty alleviation, SLM, etc.

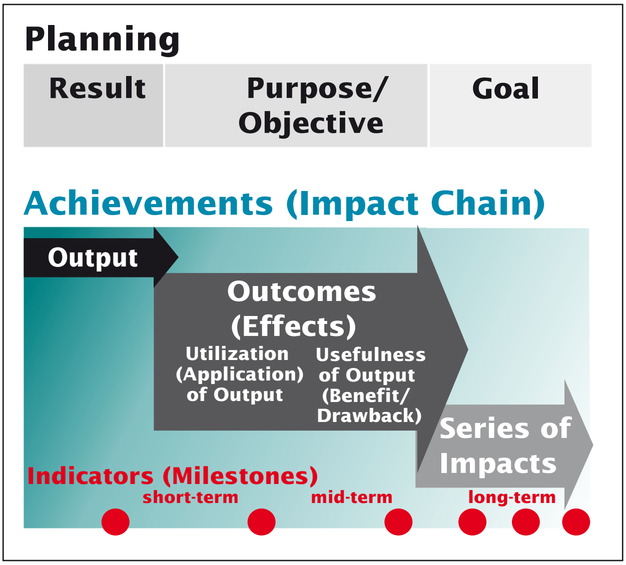


Figure 12.1: Terminology of project planning and monitoring achievements (Drawing: Karl Herweg)

12.2 Six steps of impact monitoring and assessment

12.2.1 Step 1: Involvement of stakeholders and information management

Whether outcomes and impacts are considered positive or negative, sustainable or unsustainable, etc., depends on who assesses it (a farmer, his wife, a researcher, a policy-maker, etc.), and his or her interests (economic, social, ecological). An impact may be positive in the view of some stakeholders, while others may consider it negative. Participation is a matter of compromising the various perceptions, attitudes, opinions and objectives of different stakeholders through negotiations in a real-life local context. Stakeholder diversity means managing conflicting interests but also involves a huge potential of choices to solve prevailing problems. An intervention may trigger changes in its context through its outputs. But it is the stakeholders who actually make the changes through social processes such as learning, adaptation, rejection, etc. Therefore it is necessary that stakeholders are actively involved throughout the entire IMA procedure (Step 1). Stakeholders bring their deep knowledge and perception of the context into the analysis of problems and alternatives (Step 2). They provide their views to formulate comprehensive impact hypotheses that may otherwise be overlooked by outsiders (Step 3); they provide local indicators (Step 4) and become actively involved in observation and data collection (Step 5). The term "assessment" already indicates the normative character of this method, which means that changes in a local context should not be assessed without local stakeholders (Step 6). And finally at the end of an intervention phase, it is local stakeholders who should provide new opportunities for improving the work.

IMA is not only a management tool for project staff. For local actors it can be an instrument for learning about the context in which one is involved. A strong involvement by stakeholders during the entire IMA can play a central role in their empowerment. IMA is a contribution to local capacity building because it helps stakeholders to present their perceptions, to analyze, negotiate and make joint decisions. Participatory IMA can even go much further in the sense that stakeholder groups carry out their own impact monitoring. Participatory IMA can only be successful if it is transparent and if the information collected is relevant to and accessible by different stakeholder groups. Therefore, for each group information must be presented in an appropriate and understandable form or media. The means of communication and dissemination of information are determined by the needs of each group. Finally, information must be stored accessibly for everyone who is interested in it. Some guiding questions to be answered in a participatory exercise will help to structure relevant information management: Which stakeholders should participate (local land users, women's associations, project staff, university students, etc.)? What kind of information can they provide (technical, cultural background, etc.)? What kind of information do they need / is relevant to them (technical, economic, etc.)? Which form of presentation do they prefer (reports, discussions, etc.)? What is the best way to communicate and disseminate the information (leaflets, radio programs, etc.)? How can the information best be stored so that it is permanently accessible (databases, files, leaflets, etc.)?

Seeking to involve local stakeholders in IMA, the following questions (IUCN, 1997) can be a guide:

- How are you doing, how is the ecosystem doing?
- What needs to be done?
- How would you know if things are getting better or worse?
- Where would you get that information?
- Who has the information?
- What would you need to look at in order to find out?
- What would you need to count in order to measure or find out?

12.2.2 Step 2: Problem analysis and identification of core issues

Local stakeholders involved in IMA are confronted with a large number of land management issues (household economy, social obligations, farm management, technical issues, etc.) while experts usually concentrate on their research discipline and professional focus. At first glance, all land management issues seem worthy of consideration in monitoring. However limited time and budgets make it virtually impossible to cover and monitor everything desirable. If too many details are considered, the overview may be lost and important details may not be covered satisfactorily. The most important and most relevant issues to monitor, the so-called core issues of sustainable land management, depend largely on the interests and perceptions of different stakeholders, and maybe not so much on the rather narrow focus of one group of experts. So identification of the core issues is a first crucial test of participatory impact monitoring in sustainable land management.

Problem analysis, in preparation of a development project, is often conducted under budget constraints and time pressure as theoretical exercises of experts with limited knowledge of the “area” concerned. Consequently, many projects are based on general assumptions instead of concrete know-how. Local stakeholders in particular have experiences in managing their resources. They have opinions on what needs to be done and what should be monitored. As a cross-check on these opinions, other stakeholders, for example extension agents, project personnel, researchers and local decision-makers are advised to make their preliminary assessment of what is they find important. This crosscheck will enable them to formulate their own opinion about the prevailing core issues. However, it should not be forgotten that this represents only one view and is not the only possible perception. It will provide additional alternatives for the general debate with other stakeholders, the aim of which is to reach an agreement on the core issues of impact monitoring of sustainable land management. To analyze complex systems it is recommendable to use network analysis tools (Figure 12.2) rather than isolated linear, causal assumptions.

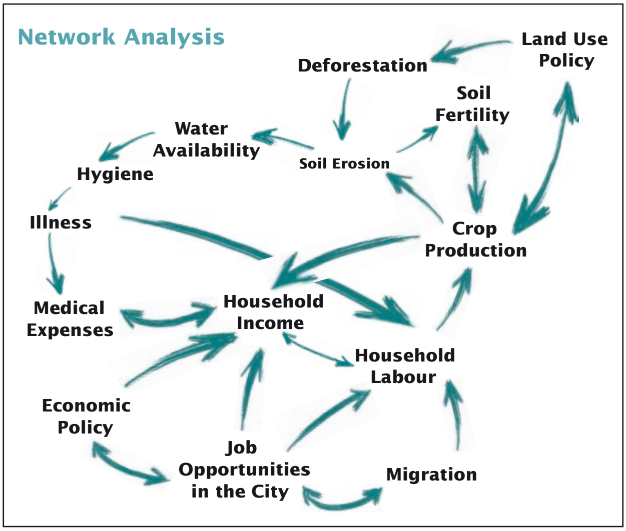


Figure 12.2: Network analysis (Drawing: Karl Herweg)

12.2.3 Step 3: Formulation of impact hypotheses

All stakeholders have their own opinion with regard to interventions that possibly improve land management and make it more sustainable. It is assumed for the most part that the proposed interventions will have a positive impact. However, experience underlines that, because sustainable land management is a complex system, any intervention will cause more than one outcome or impact, some out of which will neither be expected nor desirable! Likewise, impacts may not be restricted to the specific core issue addressed but may influence other issues as well. So before starting any intervention, it is essential to estimate different potential scenarios, the so-called impact chains, and to formulate a wide range of impact hypotheses. If this is not done, negative impacts occurring later may keep a project busy with corrective action, and the actual goal is lost out of sight.

The variety of impact hypotheses

All project or program planning documents contain only expected, positive outcomes and impacts. But such wishful thinking is fooling us, and in the end also very costly, to ignore negative impacts that are always happening. It is impossible to predict all impacts, but it is possible to think of some unexpected impacts, provided that the stakeholders concerned are involved in project planning. Even if negative outcomes cannot be completely avoided a project can be better prepared to react (Figure 12.3). Farmers, when asked what they would expect from a new SWC terrace, would definitely not be misled by the mention of only positive impacts. They would be able to anticipate certain problems that are likely to occur, such as rodents and weeds being harbored in terraces, and water logging above SWC structures.

In the following example different impacts are predicted by taking hypothetical interventions – terracing on steep slopes as a sustainable land management activity to reduce soil erosion – in a given watershed in Ethiopia:

Expected positive impacts:

- For the Bureau of Agriculture and Natural Resources, the positive impact would be e.g. achieving great area coverage of SWC technologies, reduced soil loss, and increased productivity.
- For the farmers, the positive impact would be increased crop yield and at the same time an income increased by receiving incentives and subsidies.
- For a technical project, the positive impact would be that technologies are adopted – one to one, as recommended by the project – by farmers inside and outside the project area.
- For a local small businessman, the positive impact would be an increased demand for tools and inputs so that supply of agricultural products can be increased as well.

Potential negative impacts:

- For the local farmers, negative impacts would be increased labor demands for soil and water conservation and decreased production.
- For the project (intervention), negative impacts would be that paying incentives becomes more important than the conservation focus.
- Negative impacts for merchants, could be an increased competition among suppliers.

Figure 12.3: Negative side effects (Drawing: Karl Herweg)

Examples:
Experience in SWC shows that there are always a number of unintended (unexpected and negative) impacts. For example, farmers in a watershed were assisted by a project to plant grass on contour bunds in order to provide more fodder and thatching material. Unfortunately, the grass planted harbored snakes and harmful crop pests. Farmers found that the presence of the harmful pests outweighed the benefit of the additional grass. The project is now requested to reconsider the grass program, or look into ways of managing the grass (through species selection, or cultural practices), which will minimize the effect of the harmful pests. This type of on the spot analysis of observations on unintended consequences or impacts can directly feed into the project process in order to improve the delivery of the outputs. But when deciding on corrective actions, also potential detrimental effects must be estimated by formulating new impact hypotheses.

Looking into a community in the same watershed where a certain fodder species is being introduced on contour bunds. The species was selected as an indicator of technology adoption and investment in the maintenance of the technology. At the start of the project it was assumed that increased fodder production from the recommended tree would give higher milk yields, and increase household income due to an increased demand for milk. However, later research showed that this species had a toxic side effect: Milk production increased at the expense of the reproductive capacity of the livestock. In addition, an external factor, the removal of subsidized government services made milk production an unattractive commercial venture, and therefore extra fodder production was no more required. Farmers decided to remove the fodder trees and instead planted sweet potatoes and cassava on their contour bunds, increasing the risk of destabilization of the bunds. Improving this situation would require a thorough understanding of the whole land management system rather than a hasty correction on the spot where the detrimental effect occurred.

Prevention strategy

These consequences of a SWC project and its outputs show that a great number of unfavorable or harmful outcomes could either be avoided, be minimized, or better responded to, if a sound impact chain was elaborated in a participatory manner at an early stage of a project. The impact chain is basically a series of alternative scenarios that tries to connect the outputs of a project with its project purpose (objective) or even the overall goal. The implicit purpose of impact chains is not so much to obtain a scientifically "correct" analysis of a rural context. It is rather an instrument of getting into a fruitful discussion with other stakeholders and their opinions, and thus to consider as much as possible of the unexpected. An example of how to formulate and visualize an impact chain is given in Table 12.1.

Table 12.1. Impact chain – example: soil and water conservation

Output	Outcomes / Effects				Impacts			
	Utilization	Usefulness (Benefits / Drawbacks)						
SWC technology implemented	dissemination of the technology	crop yield increase				re-investment in clothing, housing		
		fuel wood production on bunds	saved time is invested in horticulture or other productive activities	production of marketable products		children attend schools	market development in the cities	
		erosion is controlled			increase of HH income	re-investment in better farm management		decreased resources degradation
	application of water conservation	crop yield increase				re-investment in livestock		
							overgrazing	
						re-investment in alcohol		
		water-logging	yield decrease		decrease of HH income	increase poverty		increased resources degradation
		erosion increase (ill-designed SWC)		removal of SWC	sedimentation of water reservoirs	flash floods	out-migration	social conflicts

(Source: Karl Herweg)

12.2.4 Step 4: Selection of impact indicators

What indicates changes occurring in the context of the interventions introduced? How do we know afterwards, which impact hypotheses materialized? What set of indicators will point out changes that may ultimately contribute to achieve the purpose and goals of a more sustainable land management? Each element of the impact chain can theoretically be described by one ore more impact indicators, which are a simplified representation of a complex reality. The more elements of an impact chain can be formulated, the greater is the number of potential indicators. Finally this number has to be reduced to a manageable set of indicators, so that the project in question can finance and conduct the monitoring. Indicators do not only represent important components of a (rural) context but they are also means of communication between stakeholders. Thus indicators must be selected jointly.

On the one hand, it is recommendable to have a set of indicators fixed as early as possible, because this helps establish a baseline (reference) study particularly for long-term observations. On the other hand, there are good reasons to take time for this selection. For example, a newly established project does not know and understand its context and its stakeholders well. During the lifetime of the intervention the context and the views of the stakeholders change, and so will many indicators. Some of the initially selected indicators may become impractical to observe and need to be changed and replaced with some that better reflect the situation and reality of the changing context. Further, unexpected impacts may require additional indicators at a later stage. Of course, the project cannot afford to delay the definite indicator selection until the end of the intervention. But as a compromise, several months could be ascribed to the process of a participatory search for a set of impact indicators, to adapt the initial selection, and to incorporate "emerging" indicators. This is important because it documents the learning process of a project and the stakeholders who are directly or indirectly affected by it.

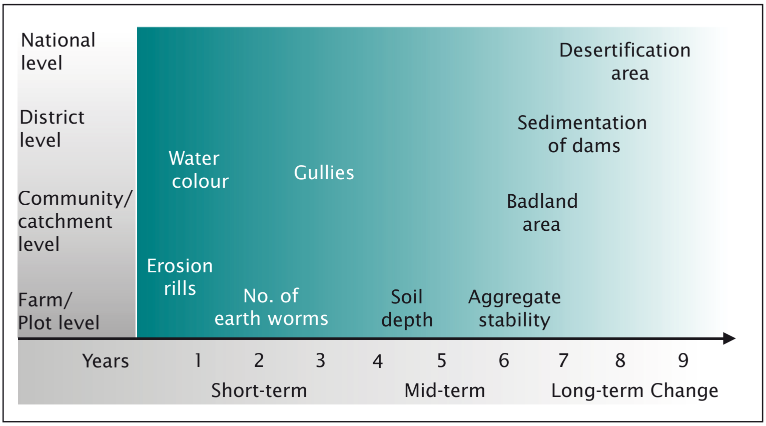


Figure 12.4: Indicator sensitivity (Drawing: Karl Herweg)

Since sustainability implies a long-term perspective, each indicator should be checked to determine whether it is sensitive to short-, medium-, and long-term changes. In the example provided in this figure the sensitivity of impact indicators is represented by the impact in terms of years after intervention, and the level at which the impact is monitored (farm / plot level, community / catchment level, district level and at national level). Indicators of short-term sensitivity (1-3 years) will be highly relevant for outcome and impact monitoring and assessment as part of the project's self-evaluation process. They are helpful for immediate correction of project activities that are taking a negative direction. Short-term indicators can also be monitored over a long period. Indicators that are not sensitive to short-, and medium term changes are more important for monitoring far-reaching or late impacts. They only help the intervention to adjust its activities after a few years, or may assist future projects to learn from the past. The extent of erosion rills, number of earthworms, changes in soil depth, and aggregate stability are considered for monitoring at the farm/plot level for both the short- and mid- term impact. On the other hand, impact indicators such as the extent of desertification area and the sedimentation of dams will be only monitored at the district and national levels.

Example:
The Mayzegzeg and Geregera watersheds are found in Tigray in Degua Tembien and Atsbi Weredas, respectively. The integrated development of the two areas has different approaches. In Geregera the Wereda Bureau of Agriculture and Natural Resources initiated the watershed development through funds obtained from Ireland Aid. SWC interventions were introduced to rehabilitate the land, increase biodiversity by excluding areas from uninhibited human interventions, and to develop water resources. The Mayzegzeg watershed, on the other hand, was initiated by the Mekelle University as a spin-off to on-going research on erosion processes and productivity. The plan of development was drawn through stakeholders' involvement at all levels. Funding was secured from Troicare and Caritas, Ireland. Extensive SWC activities are undertaken in the watershed to rehabilitate the environment, introduce vegetative-agronomic measures to improve the fertility status of the soils, introduced agroforestry species to contribute to cut-and carry system for stall feeding livestock and fuel wood production. Both projects have similar objectives and are found in similar agro-climatic conditions with variation in soil types and altitude. The question now is, what impact indicators would be suitable to monitor the success or failure of the development imperatives in these watersheds?

Literature on indicators is a good source of information but does not provide a common classification (Dumanski, 1997; Dumanski et al., 1997). Instead, there are different ways of perceiving, grouping or categorizing sustainable land management indicators (Herweg and Steiner, 2002; Herweg et al., 1998). **Generic indicators** – sometimes also referred to as **external** indicators – are based on agreements reached by external stakeholders such as project staff, researchers, development agents or policy makers. **Local indicators** (indigenous, site-specific) are mainly used by local actors and vary considerably from place to place. For a common understanding among all stakeholders, it is important to determine potential interactions or links between the local and

the generic indicators that basically represent the same aspect. For example, farmers may say that their seeding rate has increased due to overland flow, which basically indicates what researchers call soil erosion. Local indicator plants, for example, point at environmental conditions and succession processes that must exist for a longer time, at the way these conditions are related to current land use practices, and at implications for maintaining soil fertility in the area. Questions to be raised are: Are local indicators valid only for specific times, environmental conditions, and social groups? How, when and by whom are the indicators used? Are there any possible long-term relationships associated with the indicators?
A **measurement** (often **scientific**) indicator contains quantitative information based on precise and replicable measurements. **Proxy or surrogate indicators** have a more indirect relation to the issue (Dumanski, 1997) and may be qualitative or quantitative. **Experiential (anecdotal) indicators** contain qualitative and semi-quantitative information based on experiences and people's perceptions and attitudes. In general, measurement indicators emphasize objects and often show short-term impacts, whereas experiential indicators emphasize subjective views and frequently reflect long-term changes. An alternative categorization distinguishes **strategic and cumulative indicators** (Traeger, 1997). Strategic indicators show a direct cause-effect relationship where one statement or recommendation will be made for each indicator (e.g. soil fertility indicated by crop yield). The cause effect relationship with cumulative indicators is not necessarily direct, and several indicators will be required for each statement or recommendations (e.g. soil fertility indicated by soil organic matter, available N, P, K and CEC).

Impact indicators will firstly pertain to the status quo of what they represent (e.g. soil fertility, forest cover, population density). Ideally, impact monitoring of sustainable land management starts with a baseline study prior to any project intervention as a reference for comparison with future situations. Secondly, the same indicators can be used to highlight tendencies and changes if there are at least two observations (e.g. higher available nutrient content, deforestation, increasing population density). The analysis and quality of the impact monitoring in sustainable land management improves through long-term observations. Careful comparison between project- and non-project sites can substitute for time-series analyses to a certain extent. Indicators may also have a normative character because they can be used to evaluate changes (better or worse than before).

Figure 12.5: Quantitative indicators may not always be meaningful! (Drawing: Karl Herweg)

The aim is to assemble a reasonable set of indicators that can provide sufficient information to assess ecological, economic and social aspects of sustainability from the household level to the regional level. Indicators are means of communicating perceptions of sustainability among stakeholders. The type and quality of the information needed for decision-making depends on the specific situation and the expectations of a project. The following (incomplete) list of criteria and questions will assist in defining which criteria are relevant for the indicator selection process in a specific situation (Herweg et al., 1998):

- Validity and relevance: Are the indicators essential? Does the set of indicators provide sufficient information about the situation observed for making knowledge-based decisions?
- User-orientation and transparency: Are the indicators significant for different users? Are they understood and meaningful for the relevant stakeholders (farmers, land users, policy-makers, researchers, development agents etc.) who need the information? Are there local indicators that can be used? Were indicators selected involving stakeholders or not?
- Gender-orientation: Are the selected indictors sensitive enough to bring to light the domains of both men and women, so that important gender-specific knowledge bases are not neglected, bypassed or over-glossed? Are the indicators consciously constructed to address the gender issues or are they included as a cliché?
- Practicability: Are the indicators sufficient, simple, practical and effective in communicating results to and creating awareness among non-technical or non-scientific stakeholders?

- Policy relevance: Is there a sufficient number of indicators that are of importance to policy makers and address environmental issues and require a political resolution?
- Sensitivity: Does the set contain indicators that are reflecting short-term changes in land management to permit quick assessment, or do medium and long-term indicators allow assessment only after a longer time?
- Reliability: Are the indicators qualitative or quantitative so that monitoring of indicators by different persons and at different times yield comparable results?
- Timeliness: Do the indicators selected provide data that can be analyzed and presented in time for all stakeholders who need the information?
- Compatibility: Are the data to be collected and the format to be used compatible with existing data and formats?
- Cost-effectiveness: Does the indicator selection imply an agreeable compromise between precision of information, the time and equipment required or available, and the representativeness of data generated and collected?
- Feasibility: Can projects or stakeholders make the required inputs (staff, skill, time, funds) available to monitor the indicators according to the time intervals and spatial resolution agreed upon?
- Sustainability orientation: Do the selected indicators represent all dimensions of sustainability (social-cultural-institutional, economic and ecological)?
- Area coverage and hierarchy: Do the indicators reveal changes at the same spatial decision-making level (field, household, community, catchment, district, etc)?

Using a framework or model to interlink indicators

Although it is not possible to define sustainable land management globally there are attempts to address the issue internationally (Hurni and Meyer 2002). It is possible, in turn, to develop a vision of land management at the local level in terms of what is more or less sustainable compared to previous years (Herweg et al., 1998). This vision should be jointly developed with stakeholders, e.g. when planning an intervention. Since different actors have diverse perceptions of what they think is sustainable, it is not easy to select indicators of sustainability (e.g. environmental health). In contrast to this, indicators of unsustainability (poverty, overgrazing, symptoms of resources degradation, etc.) are usually easier to identify. But it must be kept in mind that the absence of indicators of unsustainability alone does not mean the land management is already sustainable. It is therefore important to use both types of indicators.

- Indicators of environmental health describe a vision of greater sustainability of land management. They help formulate goals and indicate the directions to take.
- Indicators of unsustainable land management suggest that something is going wrong and serve as an early warning system. They show the need to confront problems and issues so that time can be spent to find reasons as well as potential and workable solutions.

Indicators represent a complex reality. For example, crop yield is mostly taken as an indicator for soil fertility. However, yield is influenced not only by soil fertility but also by many other factors, including pests, diseases, weather variability, crop type and variety used, the socio-economic well-being of the farmers, etc. Therefore, single indicators cannot represent a context sufficiently. Only a set of indicators will provide plausible information on whether land management is moving towards or away from sustainability. In the framework below, SLM is segregated into "fields of observation", classified according to dimensions of sustainability and spatial decision-making levels (Table 12.2). Attribution to a particular dimension or level may vary according to the specific project context. Elements can be formulated neutrally (e.g. socio-economic disparities), as a problem (e.g. increased disparities) or as a desired scenario (e.g. decreased disparities). They can also be used in problem analysis (cf. Step 2).

Table 12.2: SLM fields of observation

Level	**Dimensions of sustainability**			
	Institutional	**Socio-Cultural**	**Economic**	**Ecological**
Household (including farm plot level)	▪ Education and knowledge ▪ Access to natural resources ▪ Household strategies ▪ …		▪ Household income, assets and consumption ▪ Labour and workload ▪ Land management and farming system ▪ …	▪ State of natural resources ▪ …
Community	▪ Local leadership ▪ Local institutions ▪ Producer and self-help organisations ▪ …	▪ Gender issues ▪ Conflict management ▪ Innovation ▪ … ▪ Social & economic disparities ▪ …	▪ Markets, prices and credit ▪ Public property ▪ …	▪ Land use ▪ Water resources ▪ …
District	▪ Education, training and extension ▪ Land and water rights, tenure ▪ …	▪ Change in social values ▪ …	▪ Employment opportunities / migration ▪ Infrastructure ▪ …	▪ Land cover ▪ Off-site effects ▪ …

Sustainable land management can be considered one of the ultimate goals and therefore envisaged positive impacts of rural development interventions. Formulated as a goal or purpose, the desired situation might be "land management is more sustainable". But there is a need to clarify what sustainable land management means. Is it increased production, decreased resource degradation, increased wealth and social wellbeing? Several dimensions of sustainability can describe it: institutional, social (socio-cultural), economic and ecological. The subdivision into dimensions prevents important aspects of sustainability from being forgotten. For practical purposes, some dimensions may be merged later on, such as socio-economic, or social/institutional. (Source: Herweg and Steiner, 2002)

Development intervention may support activities related to all dimensions of sustainability, e.g. to increase the economic and social wellbeing of the population, to strengthen local institutions, and to develop environmental protection practices. The above framework (Table 12.2) can be used to develop examples of impact hypotheses and impact indicators. It must be kept in mind that positive and negative formulations are context- and stakeholder-specific, which means they must always be adapted to the situation they are used in. Indicators are inter-linked components and processes in one land management system and not a group of separate variables. Although each single indicator could be interpreted independently, sustainable land management as an entity can only be assessed if its indicators show a meaningful linkage. Therefore, a framework or a structural model will be developed before selecting single indicators. For example, indicators such as “rainfall”, “infiltration”, “runoff” and ”evaporation” are measured in the same measurement unit of “millimeters” (mm). Thus they can be combined in a water balance equation that is, in effect, the quantitative framework or model linking the indicators to the hydrological issue of water balance (Herweg et al., 1998). In the context of sustainable land management, by contrast, one would usually select different biophysical and socio- economic indicators, of both a quantitative and a qualitative nature. The heterogeneous mix requires a qualitative frame or structural model as a meaningful linkage of indicators.

Several potential structural “models” of a complex land management reality are described in Chapter 9. Another option is given below. The Pressure-State-Response Framework (PSR: Pieri et al., 1996) is an example of a model that can be used for identifying core issues of monitoring and impact indicators. The Sahara and Sahel Observatory (1997) modified the PSR model by adding “driving forces” and identified the following topics for coverage when developing impact indicators:

- **Driving forces** causing pressure on natural resources are population pressure, economic growth, urbanization, policy failures (stagnant technology, delayed intensification), imperfect markets (lack of markets, poor market access), transaction costs and imperfect information (limited access to information about market opportunities), social inequity, poverty, and political and social instability.
- **Pressure indicators** are changes in cropping techniques, financial position of holdings, fuel wood / charcoal consumption, use of crop residues, use of animal dung for fuel, or price of fuel wood / charcoal.
- **State indicators** are the rate of deforestation, rate of soil erosion, degree of salinization, soil crusting and compaction, crop productivity, livestock productivity, and nutrient balance (on-farm organic matter recycling).
- **Response indicators** are the change of legislation, investments, tree planting, state conservation programs, farmer conservation groups, and farmer adoption of tree planting and soil and water conservation

To ensure that the indicator set covers all important aspects of sustainable land management, the indicators can be grouped, for example, according to the three sustainability dimensions (ecological, economic, social). The Land Quality Indicator Initiative of the World Bank (Pieri et al., 1996) introduced another grouping with a more economic focus that identified common (generic) and internationally agreed indicators for monitoring and evaluating sustainable land management. It is commonly known as the “5 pillars of sustainability” (cf. Chapter 9).

Still, the PSR model can be considered fairly deterministic because it emphasizes on a re-active chain of enforcement (pressure-state-response). Taking into account the high potential of indigenous knowledge, innovative creativity and individual decision-making of local land users, Hurni and Wiesmann (2002) further extended the model by adding a second string – consisting of more pro-active webs of empowerment – by pairing “pressure” with “potentials”, “state” with “dynamics”, and “response” with “innovations” (Figure 12.6).

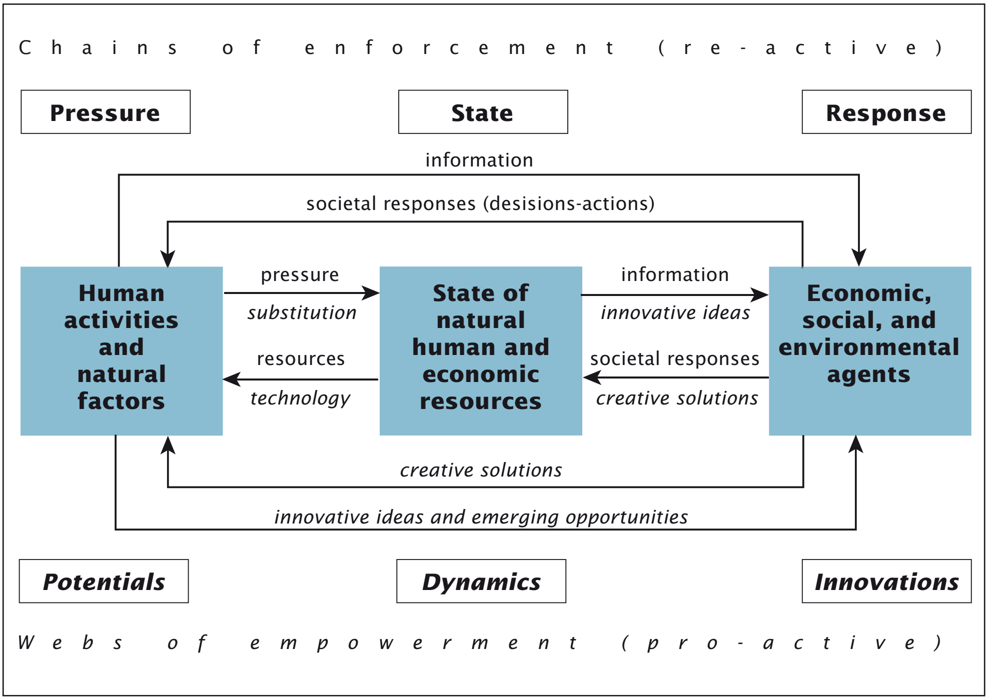


Figure 12.6: An extended Pressure-State-Response Model (Source: NCCR North-South, 1999)

Embedding the indicator criteria in a broader context

Besides the importance of an "inner" linkages to the indicator set-represented by a structural model, there is also a wider – "outer" – context to be considered:

- The **temporal** point of view: using existing data bases saves time and costs, if the specific choice of indicators, type of data, format and frequency of reporting can be made compatible. If so, this would "extend" the own monitoring period and the initial monitoring would already indicate a trend in land management. Secondary data can consist of activity and evaluation reports of institutions and organizations, information held by individuals, statistics, census results or other monitoring systems. For example, if a project needs rainfall data, the database from the National Meteorological Services Authority can extend the project information base by many years.
- The **spatial** point of view: the indicator set must reflect the fact that a project impact is not necessarily restricted to the project area (on-site) but may reach further (off-site). For example, where terraces are applied (on-site), they may affect the amount of water, soil and nutrients that leave the watershed. Thus people living downstream (off-site) are also affected by these technologies. The selection of representative monitoring locations will help reduce the costs of on-site and of-site impact monitoring of the sustainable land management.
- The **hierarchical** point of view: local indicators are site-specific, which may limit the aggregation of information at national level. Nonetheless when selecting local indicators, consideration should be given to whether and how they can possibly be aggregated to become an even more useful tool for decision and policy-making. For example, a local indicator such as the color of plant leaves can be calibrated with generic soil fertility indicators such as nutrient deficiency, which can be accounted for in terms of cost . In this case, these indicators are useful for calculating the relevance of resource degradation for a national economy.

12.2.5 Step 5: Development and application of impact monitoring methods

How can a rural context – represented by a selection of impact indicators – be monitored and changes be documented? Which methods are applicable within the means and capacities of the intervention? How can methods best be combined? There are usually several ways and methods of monitoring a parameter or an indicator. If highly accurate (scientific) data is required, it is assumed that projects will call upon specialists who will apply their own methods. In the event that development interventions do not have the capacity and resources to apply sophisticated methods, a project will have to rely on cost-effective monitoring tools that can be handled in a flexible way by project staff themselves.

In what follows, three types of monitoring methods are described which have a high chance of being applied because they are built on what many projects already practice (Bosshart, 1997d; Germann et al., 1996; Pretty et al., 1995). These tools can be considered the basis for impact monitoring and assessment, but must also be adapted to the specific context of the intervention in question; in accordance with the impact hypotheses formulated and impact indicators chosen. Therefore, only general descriptions and explanations are presented here.

Triangulation

How good is the quality of the information obtained by the above-mentioned methods? It is assumed that, due to resources limitations, not all projects can afford methods with high accuracy. Therefore the principle of triangulation is used, which combines reliability with participation. This means that all individual perceptions, which are obtained through interviews and discussions, must be crosschecked with the perception of others and, if possible, compared with direct observations.

- **Interviews and discussions** with local stakeholders are the basis for IMA. The information obtained can be very detailed but will be guided by individual perceptions and the different (often hidden) agendas of the stakeholders. Although all kinds of visible and invisible changes might be discussed, socio-economic aspects may dominate. A crosscheck of the information, in particular invisible (e.g. social) changes, can be made through interviews with other stakeholders. Visible improvements or deteriorations can be crosschecked with photo-monitoring and participatory transect walks.
- **Observations** made and discussed during a **participatory transect walk** provide a detailed view, especially of biophysical issues, although social and economic issues can also be addressed. A transect walk highlights the spatial interrelations of soil degradation, and nutrient, water and energy flows, etc. Discussions often start with visible aspects but can ultimately include links with invisible aspects. A transect walk is an excellent opportunity to identify local impact indicators. The information can be crosschecked with interviews and photo-monitoring.
- **Photo-monitoring** provides an overview of visible changes in the project context, which may be predominantly related to biophysical and economic issues. But photos require interpretation and further investigation of the background. This can be done through interviews and discussions, as well as during participatory transect walks, depending on which aspects need further clarification.

Interview and discussion

Interview and discussion as participatory tools cover quite a wide range of indicators. They usually produce qualitative results and also serve as a cross–check on quantitative results, for example from structural interviews or biophysical measurements.

The tools are used best in combination with complimentary approaches and methods (triangulation) to ensure the quality of information appropriate for decision-making (Van Veldhuizen et al., 2000; Pretty et al., 1995; Schönhuth and Kievelitz, 1994; Werner, 1993; Bollinger et al., 1992; FAO, 1990; Albrecht et al., 1989; Chambers et al., 1989).

Almost all biophysical and socio-economic indicators can also be monitored by obtaining peoples' opinions of them. Discussions can encompass, for example, gender aspects, labor division, workload, wealth, production and market prices, household income, land use and land management, resource degradation and protection, technological and management innovations, etc. Packages such as RRA (Rapid Rural Appraisal), PRA (Participatory Rural Appraisal), and PLA (Participatory Learning and Action) contain many well-tested and cost-effective tools consisting of group exercises, semi-structured interviews, informal discussions and visualization (mapping, modeling, rating matrices, causal diagramming, mind-maps). They are characterized as rather qualitative approaches combining "optimal ignorance" and "appropriate imprecision". These methods were primarily designed for mutual learning, and therefore assist local people to gain confidence in conducting their own appraisal and analysis and help external experts to understand local perceptions.

Potentials of the method	**Limitations of the method**
Can be used during all phases of an intervention	Statistical evaluation is not necessarily ensured, data need verification by other methods
Can cover a wide range of indicators	Depends a lot on the behavior, attitudes, values and beliefs of the surveyor; therefore, quality control is necessary to avoid abuse and to maintain certain professional ethics
Comparatively cost-effective, rapid, qualitative approach Integrates local (indigenous) and external knowledge	Depends a lot on the behavior, attitudes, values and beliefs of the surveyor; therefore, quality control is necessary to avoid abuse and to maintain certain professional ethics
Allows in-depth investigation into issues raised by all	PRA methods have to be accepted and must be applicable by local stakeholders
Hidden and glossed aspects of discussions can be discovered that are not obvious at first glance.	Exaggerated, standardized and routine use of participatory methods will saturate people and result in response fatigues
	Even if the methods and tools are allegedly participatory, there must be reflection about what ends are really served by the results

Participatory transect walk and observation

The fact that interviews and discussions with people bring to light useful information for IMA should not lead to the conclusion that direct observations and measurements by project staff or outsiders are no longer necessary! Particularly biophysical and some economic aspects can be directly observed in the field to crosscheck the results of other methods. A checklist of potential indicators of unsustainable land management is given in Table 12.3. Naturally, such a list must be adapted and possibly supplemented when applied in a specific local situation. A participatory transect walk will not only provide a detailed view of a farm or valley, critical sites of resource degradation and areas of promising management. It will also help to establish connections between those sites, i.e. flows of nutrients, water, sediment and energy. Thus regular transect walks, as well as farm and field visits are not only recommended to maintain close contact with local stakeholders and their reality. Different indicators and parameters also require different observation times. For example, pests and diseases are observed during the cropping season, production during harvest, soil degradation at the onset of a rainy season, water shortage during the dry season, etc.

A participatory transect walk is conducted by a team to observe and talk about issues of local importance. Experts (outsiders) and local informants (insiders) systematically traverse the area under study. This team is preferably composed of people representing different disciplines (biophysical and socio-economic) in order to cover a wide range of topics during the walk. The walk follows a specific route, e.g. from the highest to the lowest point in the landscape, from the north to the south or east to west which ever is agreed upon initially by the group. Everything mentioned by the informants and everything observed and questioned by the outsiders is discussed and noticed. The walk supplements information obtained from officials and secondary literature during preparation of the monitoring with subjective and lateral observations and experiences. This method can be used for a qualitative approach as well as for a rapid semi-quantitative assessment.

The participatory transect walk is of particular interest because it gives the opportunity to obtain an overview of perceptible signs of resource degradation that indicate unsustainable land management and pose questions like: Which degradation processes prevail? When do they occur? Where are the areas of particular hazards (hot spots)? Such indications are a starting point for further informal discussions with local and other stakeholders on the spot, and consequently for understanding different perceptions of the same issue. Socio-economic topics are already subject to interviews and discussions, but may also be taken up during the walk.

Procedures in undertaking participatory transect walks:

- Local informants are asked to form an observation team together with outsiders. It is important to have representatives of all stakeholder groups concerned. Development agents with a background in natural resources management are of particular interest since they would have a good perception of the prevailing situation. In the absence of such a subject matter specialist, an agricultural extension agent with strong orientation on land management would be preferable.
- The route is identified by the group, which needs to consider areas where major agricultural activities are undertaken and include different types of land use.
- The team should develop its own norms for group behaviors as a checklist of ensuring participation and meeting of individual responsibilities and team obligations.
- The transect walk is planned by defining the subjects to be covered, methods to be used, information and data to be collected. To identify, for example, indicators of unsustainable land management, checklists to be developed will give initial hints about what to look at. Discussion prior to and during the walk may give further clues about observable symptoms and indicators.
- The timing of the walk depends on the subjects of interest. For soil erosion observations, this can be done where and when erosion indicators are visible, which mostly coincides with the beginning of the rainy season. Crop pests and diseases are preferably observed during the major cropping season, crop yield before harvesting, water problems during dry and wet seasons, and soil fertility during the early flowering stage of the crops.
- During the transect walk new findings are considered and pursued if they seem to be of importance for the overall subject. For example, certain farmers may have introduced a new variety of crop, tried to divert run-off into their farm, opened a pond for harvesting and collecting flood water for supplemental irrigation, etc.
- Different land units (slope, level terrain, forest, cropland, natural sites, villages, etc.) and problematic areas (erosion hazard, water shortages, malaria infestation etc.) are distinguished. During the walk, relevant observations are marked on the map and accompanied by extended remarks and descriptions in a field book. Sketches of the area enhance detailed observation more than photos. Like photographs, sketching can be used to visualize impressions or changes after a certain period of time.
- Symptoms of unsustainable land management, for example, will be observed within their topographic sequence, with a continual search for possible interrelations or causes of degradation up- and downslope, or up- and downstream.
- nformation is shown on a general transect map. Sketches, photos and notes are used to reflect on the mapping and for discussions with others who did not see the location. Sketches and digital photos can be used on the same day, while conventional photos may take longer to be developed. In view of the long-term nature of impact monitoring and assessment, field maps may need to be redrawn on clean paper while the field impressions are still vivid, preferably on the evening of the field day.

Potentials of the method	Limitations of the method
Provides a good overview and rather intensive impression of a new location	Subjective information; mapping reveals only what is visible to the person who applies the method
Closely considers the local knowledge base	Qualitative statements, in particular, must be supported by additional investigations
All local land users can participate	
Important new issues arise which may have been overlooked	
Provides basically qualitative results, but some indicators can be quantified	
Signs of unsustainability land management can be mapped within a topographic sequence, which reveals spatial interrelations of biophysical and socio-economic processes	

Table 12.3: Participatory transect walk and observation checklist: Signs of unsustainable land management

Signs of unsustainable land management	**Indicators (what to observe)**	x
Soil fertility decline	changing color of plant leaves	
	reduced plant cover / production	
	salt on soil surface	
	abandonment of cropland	
	soil color changes	
	decreasing root density	
	poor soil drainage	
	compaction: crust thickness, strength (break by hand)	
	indicator plants	
	…	
	…	
Degradation of plant resources (possibly as a consequence of soil / water degradation)	changing color of plant leaves (yellow)	
	pests and diseases	
	low plant ground cover (estimation in %)	
	low variety of plants / high variety of weeds (species composition)	
	…	
	…	

Table 12.3 cont.

Soil erosion by water	exposed plant roots (cm)	
	rills, gullies and accumulations (No., density, volume)	
	reduced topsoil depth (spade or drill)	
	change in soil color indicates subsoil exposure	
	increasing runoff, periodic flash floods (time)	
	sedimentation of reservoirs, deposition visible during low water table	
	water turns brown	
	increased seeding rate	
	increasing stone cover (topsoil already washed away)	
	...	
	...	
Wind erosion	dust storms, mobile dunes (pegs as reference points)	
	nutrient depletion (incl. acidity), toxicity (pH)	
	...	
	...	
Declining water quality and quantity	water has brown color (soil erosion)	
	algae	
	bad odor	
	months of water shortage	
	diminishing groundwater table	
	drying up of wells, springs and rivers	
	dying trees	
	more unpalatable weeds – fewer fodder species	
	...	
	...	
Degradation of animal resources (possibly as a consequence of plant degradation)	changing No. of livestock per household or village	
	malnutrition / shortage of fodder	
	animal diseases	
	...	
	...	
Land use changes	increasing % of cropland	
	deforestation	
	shortening fallow period	
	pasture turned into cropland	
	...	
	...	

... list of indicators should be supplemented (Source: Herweg and Steiner, 2002)

Photo-monitoring

Development co-operation is intended to initiate changes, and at least some of them should be visible after a couple of years. Rural development projects, for example, should enhance household income and living standards, which would then be visible in terms of better housing and clothing, more children going to school, better means of private and public transport, etc. Similarly, if land and resource management has become more sustainable, it should be evident in improved crop stands, controlled soil degradation, effective conservation measures, etc. Photo-monitoring is a comprehensive method for documenting all visual changes that can be used to cross-check individually perceived changes.

Several series of photos from specific locations and standpoints taken at different times over a longer period will document how things change. Photo documentation can range from overview pictures (e.g. showing an entire slope, valley, farm, village, etc.) to detailed views of specific objects (houses, rooms, people, conservation measures, etc.). Where changes are intended and expected, photos can be taken from permanent standpoints at regular time intervals. Complementary photos can be taken occasionally wherever and whenever unexpected visible changes occur. However, photos alone do not tell much about how and why changes occurred. They provide an overview that requires further discussion and interpretation with stakeholders at regular intervals.

Potentials of the method	Limitations of the method
comprehensive and fast method	restricted to visual changes; should be used together with other monitoring methods
professional manpower or sophisticated equipment would improve the quality but are not necessary (reflex camera desirable, but pocket camera can also be used)	

12.2.6 Step 6: Impact assessment

Preparing the benchmarks (reference values) for each impact indicator in view of impact assessment

How did the context change in the eyes of the stakeholders? What did they learn from these changes? Are the changes positive, negative, satisfactory or not, how did changes happen? Assessment is a process of individual judgment that will reveal many different opinions. Changes in the context of the intervention will then be visualized, for example in a “spider” or “amoeba” diagram (Herweg and Steiner, 2002). For this purpose a rating for each indicator is inevitable, e.g. the best possible realistic achievement for each indicator is 5 (very good), and the worst possible achievement is 1 (very bad). It is recommendable to prepare the benchmarks for rating of each indicator already during indicator selection (cf. step 4) in a debate among all stakeholders. For example, farmers would know how to rate the impact indicator "maize crop yield" from "5" (e.g. > 3 t/ha) to 1 (e.g. < 1 t/ha). Ideally, all stakeholders agree on a common rating for all impact indicators (Table 12.4). But it can also be interesting to carry out impact assessment separately for each stakeholder group, and each group's findings will be communicated to the others. It should be determined at what level the assessment will be made (household, community etc.)?

For example, if there is a great heterogeneity of household categories (such as poor and wealthy households), which in Ethiopia is rather the norm than the exception, changes in the farm context should be assessed individually, or at least separately for

Table 12.4 Example: benchmarks for interpreting impact monitoring results prepared in a participatory manner for each indicator (Source: Herweg and Steiner, 2002)

Impact indicators	**Rating***				
	5 Very good	**4 Good**	**3 Moderate**	**2 Bad**	**1 Very bad**
Short-term indicators Crop yield (maize)	> 3 t/ha	> 2 - 3 t/ha	> 1.5 – 2 t/ha	1- 1.5 t/ha	< 1 t/ha
Household income	>20 % increase	> 10 – 20 % increase	1 – 10 % increase	stagnating	decreasing
Women's labour income	>20 % increase	> 10 – 20 % increase	1 – 10 % increase	stagnating	decreasing
% of farmers adapting new technologies without incentives	> 60 %	> 40 – 60 %	>20 – 40 %	10 – 20 %	< 10 %
Occurrence of pests & diseases	no	rarely, little evidence	sometimes, but can be controlled	control is often difficult	high, every year
Soil erosion (rills and gullies)	no signs of erosion	smoothened soil surface, but no rills	sometimes, few rills	most years, many rills	every year, rills and gullies
Mid- to long-term indicators					
Households decision-making	**jointly in most households**		**jointly in a few households**		**by men in most households**
% of farmers experimenting with cropping practices	regular modifications by > 70 %	regular modifications by > 50 - 70 %	regular modifications by > 30 - 50 %	irregular modifications by 5 – 30 %	< 5 %
Boys and girls with school leaving certificate	> 80	> 60 - 80	> 40 - 60	30 - 40	<30
Soil fertility status**	Deep, dark topsoil, high earthworm activity, high root density		moderately deep and dark topsoil, earthworm activity, root density		Light soil colour, yellow & red plant leaves, no earthworms, low root density

** N.B: the rating is highly site-specific and requires intensive discussion with stakeholders*

*** Rating of soil fertility status requires consultation with soil specialists* each household category (Atakilte et al., 2001). If all households are judged together at the community level, the result will be an average. This average, however, may not reflect important changes in individual households. It will thus be meaningless. After a set of important indicators is selected, an initial observation (monitoring) that takes all of them into account produces the baseline. In the next years to come, monitoring and assessment will only include those indicators that are sensitive to short-term changes. Indicators of medium- and long-term changes can be gradually added after several years. Using the spider diagram (Figure 12.7) for visualizing the results of the monitoring, the questions “where are we?” and ”where do we go from here?” need to be asked in relation to each selected indicator. A comparison of a recent rating with previous ratings will naturally reveal indicators with detrimental development, or in which no or little “improvement” is considered. In our example (Figures 12.7, Table 12.4) this is the case for the indicators “boys and girls with school leaving certificates” and “household decision-making”. When interpreting such figures, the first reaction is mostly to give special emphasis to improving these sectors in the future. Unfortunately, the inherent consequence of this interpretation is often to neglect the other indicator with seemingly better outcomes, which may be a fatal mistake. It should always be kept in mind that the rural context under questions works like a system where all factors are connected, and where improvements of the entire system cannot always be achieved by direct interventions focusing on the weak points. For example, better education and empowerment of land users can contribute as much to SLM as an appropriate technology. Therefore, while interpreting monitoring results, it is a must to reconsider – or even modify – the systems analysis that was done at the beginning (cf. IMA Step 2)!

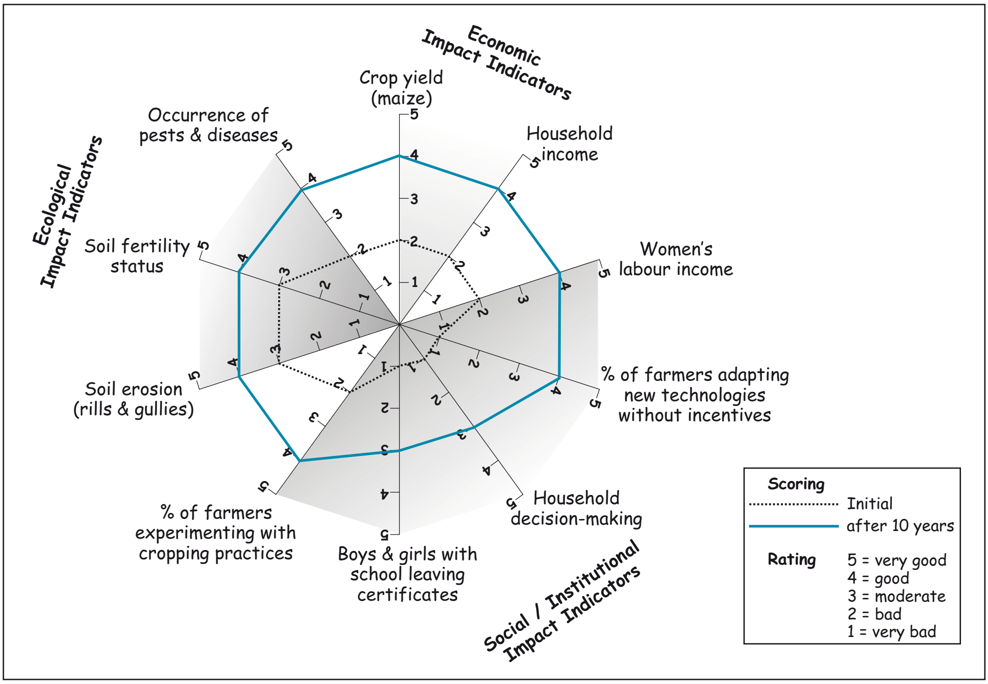


Figure 12.7: Spider diagram to visualize changes in the indicators observed (Source: Herweg and Steiner, 2002)

Trying to attribute an impact to a project

While local stakeholders may very much care for a better livelihood in general, they may be less interested to know which project made which contribution to it. A donor, however, needs to justify the own investment in front of its parliament and tax payers back home. Naturally, the spider diagram can only reflect changes covered by selected impact indictors. How can these changes be attributed to an individual intervention or project? Were there additional changes that were not expected and, therefore, could not be monitored? Which changes contribute to the goal of the project? We have to keep in mind that, the longer an intervention takes, the more factors other than the project in question will contribute to changing a rural context. This make it more and more difficult to attribute the new situation to a single factor, such as the project in question, another development program, the national agricultural policy, the world market price, etc. This is referred to as the attribution gap (Figure 12.8). Even with costly investigations such as basic research it will be difficult to precisely tell what exactly a specific intervention has contributed to the change of the context. Therefore, in most cases the challenge is to find plausible relations between the project's outputs and the changes rather than scientific proof.

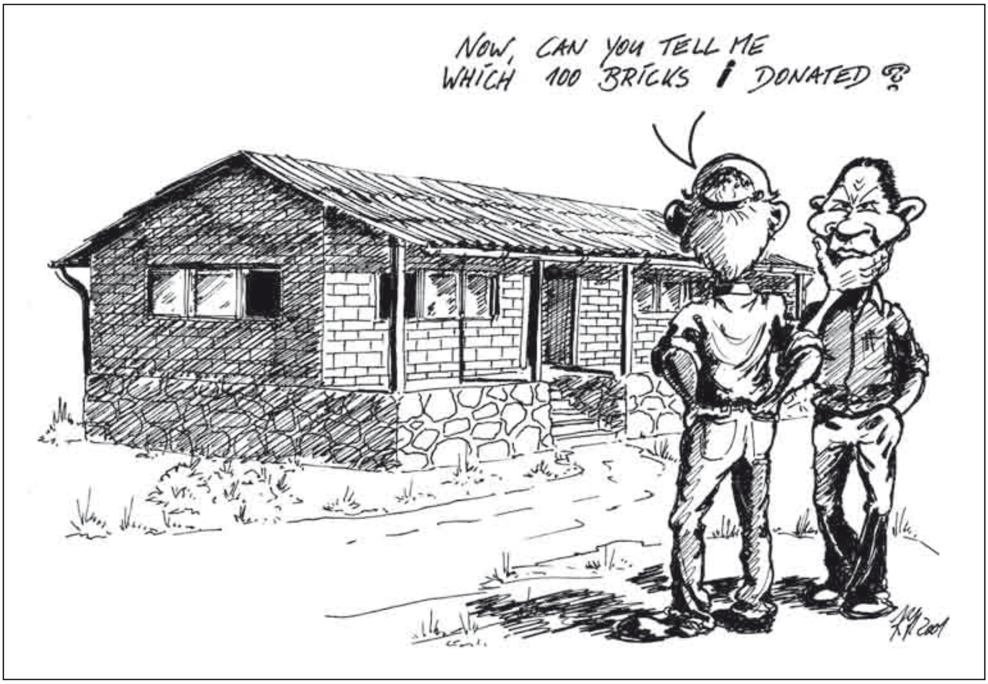


Figure 12.8: Attribution gap (Drawing: Karl Herweg)

At this point it is important to reflect about the “nature of change”. Changes in a context can be considered the result of social processes such as learning, adaptation, communication, decision, integration, etc., i.e. interactions between individuals or groups. The project – or the intervention – “only” tries to trigger or strengthen such processes with its outputs. For example, any new technology must be utilized and found useful (or useless) to be finally adapted or rejected by stakeholders, which is the result of a learning process. Members of a society communicate their experience and learn from it. When the biophysical environment or the economic situation changes, people adapt their perception and react to it. Our hypothesis is, not a technology as such makes a change, but the social learning that is related to its application! Therefore, a key question of impact monitoring is, whether a project was able – through its outputs – to stimulate changes and social processes such as learning, and whether these processes are likely to help reach development goals.

The following guiding questions can be helpful in attributing changes to project actions (the first two questions have to be answered by stakeholders, the last three questions are subject of interpretation):

- What changes do the stakeholders **recognize** since project activities were started (at the household level, at community level, at other levels)?
- What did stakeholders **learn** during these changes?

- By mentioning lessons learnt stakeholders point towards important social processes. Which **social processes** do they indicate (individuation, self-determination, empowerment, innovation, adaptation, ethnic integration, participation, social learning, etc.)?
- What **plausible relations** can be determined between the project **(intervention)**, the **social processes** and the **changes** in the context? Would the changes have occurred anyway, i.e. even without the project? Which factors have – alone or in combination – contributed to the changes (the project in question, external factors such as policies, other projects, etc.)?
- What is the **connection** between the **social processes** and the **(development) goals**? Which processes should specifically be strengthened in future, which ones better be avoided?

Different examples are provided in Annex 2 to give the reader an indication of the levels where the indicators are to be applied and the sensitivity of the indicators at a given level. The examples are only a guide, i.e. that the formulation of the impact indicators needs to be adapted to the specific area of intervention!

12.3 Questions and issues for debate

All development programs set highly ambitious goals, such as poverty alleviation, sustainable management of natural resources, empowerment of marginalized people, good governance, advancement of women, etc. Although many development activities can be called successful at a local scale, the big goals (e.g. the Millennium Development Goals) are not yet reached, despite more than four decades of development cooperation. What do you think why not, and how to estimate the probability that these goals will be reached in the future?

13. Decision Support System for Soil Erosion / Soil and Water Conservation

Data and information on soil erosion and soil and water conservation studies undertaken in the highlands form the basis for the Decision Support System (DSS) presented here. Besides quantitative erosion data, semi-quantitative information and qualitative observations, the DSS contains basic ideas that do not automatically emerge from research but that are based on normative concepts and values. These must be challenged from time to time and be subject of continuous debate. For example, the DSS is based on the assumption that the prevailing land management is unsustainable (showing indications of resource degradation) and that the vision or goal is a more sustainable land management. The term “sustainable”, as explained in the previous chapters, reflects a normative concept, a development goal that was globally agreed upon in the 1980s.

The DSS is mainly addressing SWC extension staff and experts (team leaders, planners, decision makers). It must take into account ethical principles as well. For example, an extension agent who has to fulfill the job of implementing SWC might consider the participation of local land users as an obstacle because it involves numerous consultations, negotiations and possibly conflicts. However, since it will finally be the land user, his family and livelihood that will directly be affected – possibly not only in a positive sense but also by negative side effects – we feel that active participation is an obligation, not a good-will activity of experts and extension workers. This particularly will be more important in communities that are highly decentralized and empowered to make the actions of the extension agent accountable to them.

How to deal with research findings? Some general remarks:

- Biophysical environment and socio-economic framework are diverse and both are subject to changes. There is no standard situation, so do not look for standard solutions or a standard design for SWC measures. There is also no standard criterion for success but there are some guiding principles. SWC must meet the needs of a changing situation; it must be flexible.
- Research findings need to be taken as guiding principles, not as a cooking book. They do not free extension staff and experts from making their own decisions.
- Research findings are not a substitute for land users’ involvement. Their participation in decisions concerning their properties is inevitable.
- Research findings help to prepare the argument for a discussion with land users; they do not replace the argumentation.

Until now, neither indigenous nor external (scientific) approaches alone could solve the problem of erosion. The goal is a suitable and acceptable compromise between both. The following procedure is strongly recommended:

- start from the indigenous knowledge and technology, because it is already accepted and fit into the prevailing land management system;
- look out for the most promising indigenous components or technologies;
- look for incremental improvement of these jointly with land users, use their creativity, enhance access to information;
- do not try to solve all in one go, encourage farmers to experiment;
- do not restrict yourself to permanent measures, allow more flexible solutions;
- Do not regard land users' as the problem but as part of the solution.

13.1 Overview

Starting Point: Unsustainable Land Management
Goal: Increasingly Sustainable Land Management

Problem Identification (unsustainable land management in general) - *Key questions:* What visible symptoms of unsustainable land management can be observed? How do farmers perceive the sustainability of land management?

Tool	Message / Example
Participatory Transect Walk and Observation Checklist: Signs of Unsustainable Land Management	Resources degradation: ▪ nsoils: nutrient leaching, salinization, soil erosion, acidification, toxicity, compaction, ... ▪ water: water quality decline, water shortage, flash floods, ... ▪ plants: plant diseases, reduced biodiversity, reduced plant cover, ... ▪ animals : animal diseases, over-stocking, ... Unsustainable Land Use ▪ cultivation of marginal land ▪ mono-cultures ▪ over-grazing ▪ deforestation ▪ shortened fallow period Societal processes ▪ out-migration ▪ impoverishment ▪ malnutrition, famine ▪ increasing social disparity ▪ conflicts over resources

Problem Identification (soil erosion in particular) - *Key questions:* What visible symptoms of soil erosion (degradation) can be observed? What do farmers perceive as problem? How do farmers perceive erosion?

Tool	Message / Example
Observation of soil erosion features (indicators of unsustainable land management)	past erosion ▪ exposed tree roots ▪ changes of soil color ▪ gullies ▪ soil surface steps, separating cropland from other land use types ▪ land slips, land slides ▪ … (local indicators) current erosion ▪ smoothened soil surface (splash, sheet erosion) ▪ rills, gullies ▪ accumulations ▪ brown rivers ▪ … (local indicators)

Problem analysis - *Key questions:* When, where and why does erosion occur? What triggers soil erosion processes?

Tool	Message / Example
Identify interrelation of *direct factors of influence*	▪ vegetation ▪ topography ▪ soils

Search for solutions - *Key questions:* Which principles of functioning are relevant in the given situation? What indigenous knowledge and technologies – with SWC functions – are available? What are the potentials and limitations of successful SWC? Who should be involved to strengthen potentials and minimize limitations? Why are land users not in a position to solve the problem by their own means now?

Tool	Message / Example
Recall SWC *principles*	▪ wind erosion control ▪ vegetative-agronomic SWC (maintain cover and soil structure) ▪ structural soil conservation (control drainage) ▪ water conservation
Explore local *potentials (wealth rank)*	▪ indigenous household strategies (on-farm, off-farm) ▪ indigenous SWC technologies, their potentials and limitations
Determine *factors limiting* a more sustainable land management	▪ limited labor, time, capital, training ▪ etc. insecure tenure ▪ limited infrastructure ▪ no access to market ▪ cultural taboos ▪ etc.
Document and evaluate SWC approaches and technologies	▪ WOCAT

Impact assessment - *Key questions:* (After implementation) Which SWC technologies are working well (less erosion, stabilized production, integrated into the prevailing farming system)? What kind of problems can be observed or are reported, and why do they occur? Are there potentials for improvement?

Tool	Message / Example
Formulation of *impact hypotheses (impact chains)*	▪ participatory formulation of positive and negative "visions" of different stakeholders
Search for *impact indicators*	▪ ecological ▪ economic ▪ social (cultural)
Evaluate SWC approaches and technologies	▪ WOCAT
Impact assessment *(spider diagram)*	▪ participatory ranking of indicators ▪ mid- to long-term impact (effect, outcome) on SLM

13.2 Detailed consideration of soil erosion and SWC

13.2.1 Climatic considerations in SWC

SWC technologies vary according to the following climatic zonation:

- **Semi-arid**
  The main problem is moisture stress and therefore, water conservation or water harvesting is of top priority. Since the long dry season limits the application of vegetative-agronomic measures structural SWC are the basis for intervention. Structural measures without gradient (on the contour) have the best water retention performance, however, they may break during heavy rainstorms. Therefore, a slight gradient and spillways are recommended to drain excess water. The spillways must be designed in a way that a straight downslope water flow is impossible.

- **Sub humid with reliable high rainfall periods**
  The main problem is soil erosion or nutrient leaching. Vegetative-agronomic SWC measures have top priority. Particularly at the on-set of the rains when vegetative-agronomic SWC is not yet protective after a longer dry spell, structural SWC must ensure a controlled drainage of excess water. High rainfall areas demand for a proper drainage system, which encompasses cut-off drains, graded structures and waterways.
  Attention:
  - The structures reduce the area for crop production considerably. This reduction increases with the slope angle. Thus, agronomic measures to increase crop yields are inevitable.
  - Pests and diseases are a common problem occurring with structural SWC and must be taken care of through integrated pest management (IPM) strategy.
  - Drainage ditches or structures with a gradient of below 5% may cause waterlogging.
  - Drainage ditches or structures with diminishing gradient cause overflow and rill erosion.
  - Drainage ditches or structures with a gradient above 15% may lead to gully erosion.

- **Sub humid with high variability of rainfall periods**
  Moisture stress and soil erosion may both occur within a short period of time. SWC interventions must therefore be prepared for both extremes. The variability of rainfall limits vegetative-agronomic SWC. Structural SWC measures must be graded to accommodate the wet spells, supported by breakable tied ridges and/or infiltration ditches to be prepared for the dry spells. Cut-off drains and waterways are inevitable to control extreme runoff.

13.2.2 Critical locations

Critical locations are places

- where erosion occurs, this is, where you can observe the damage
- which contribute to erosion, even without being damaged themselves

Critical locations are places are marked by several indicators

- Changes in soil color, bare roots of trees, lowered field borders and old rills (partly vegetated), gullies and accumulations indicate former erosion processes.
- More important indicators are current (or recent) rills, gullies and accumulations because they point at recent erosion processes.
  - Rills and gullies imply soil losses, which are usually by orders of magnitude higher than sheet erosion losses. Soil, which is transported by sheet wash, may be accumulated within a few meters, but soil washed through a rill is transported further away and is mostly lost. In addition, rills remove a large portion of the topsoil and all seeds at once. Starting from a single rill or gully, erosion spreads both in width and in depth and may severely hamper farm operations if it is not controlled.
    - Generally, rills and gullies are likely to build up along slope depressions, but they can occur on any slope angle and slope shape.
    - Fields with cereals are often more prone to rill erosion than fields with pulses.
    - The occurrence of rills under SWC shows you where the measures are not efficient and need improvement.

  - Rills and gullies mostly occur on cropland, but they may be caused by other factors outside the cultivated area. Critical locations which contribute to erosion by collecting and directing overland flow are:
    - Roads, footpaths, animal tracks and villages because the surface is sealed; infiltration is thus prevented and an artificial catchment is created. If runoff is not properly drained, it may be diverted to crop land (runon) and cause damage.
    - Slope depressions that directly mark the flow direction of water and always need careful observation.
    - Even grassland and wood land which produce sufficient runoff to create damage on cropland downslope.

  - Erosion on cropland may cause subsequent damage further downslope:
    - Adjacent crop or pastureland may face erosion rates higher than expected.
    - Accumulations burying crops and seedlings.
    - Field border erosion results from water concentration between two fields and affects farm operations if it is not controlled.

– Pollution of and damage to roads, footpaths, village area and other infrastructure.
– Pollution of rivers and watering point may affect water quality and public health.
– Sedimentation of water reservoirs may cause water shortage.
– Flash floods may affect people living in the valley bottoms.

Critical locations		**Actors involved**
Upslope	roads, settlements footpaths, animal tracks, pasture land, woodland	engineers, villagers land users land users
On crop land	inappropriate management defective SWC	land users land users, extension staff
Downslope	field borders, crop land, pasture land watering points water reservoirs rivers and valley bottoms	land users land users land users and urban dwellers land users and urban dwellers
Consequences	water quality decline water shortage flash floods loss of crop land and production public health and security endangered	public public public public public

- Critical locations are direct causes or contributions to erosion damage, and they often imply hidden reasons. It is worthwhile to investigate, for instance, why a road has improper drainage, why cut-off drains did not protect fields sufficiently, or why SWC measures are ill designed or not maintained. It becomes clear, that SWC is not only a matter of agriculture, training of extension staff or motivation of land users, but also of urban planning or road construction.
- In turn, SWC reducing soil losses may improve the water quality and thus imply benefits also for urban dwellers. They should be made aware of this and should take part in SWC, e.g. sharing its costs, not only its benefits.
- The discussion of the critical locations has shown that soil erosion is to a large extent a drainage problem, the solution of which must involve all land users within a micro catchment. A single gap in the drainage system may cause even greater damage.
- Likewise it is important to know that ill designed SWC structures will lead to a breakthrough at the weakest point. This concentrated runoff may cause more erosion than there would be without SWC at all!
- Even if SWC is well designed, lack of maintenance can result in the same effect.

13.2.3 Timing of SWC

As a rule of thumb, about 80% of the annual soil losses are caused by only 20% of the annual rainfall events! Crosscheck with a meteorological station nearby when highest rainfall and highest intensities can be expected and plan SWC activities ahead of this time.

- At the beginning of the rainy season with no or low vegetation cover, rainfall of medium erosivity is sufficient to cause severe erosion damage. In the absence of cover, structural SWC measures are needed.
- During the middle or towards the end of the rainy season with higher vegetation cover, rainfall with high erosivity can still cause high soil losses, particularly in connection with rill erosion. Despite the efficiency of vegetative-agronomic measures, structural SWC measures are still useful in support of the vegetative-agronomic interventions.

13.2.4 The role of vegetative-agronomic SWC

Vegetation is considered the best and at the same time the most productive means to prevent soil erosion:

- vegetation cover prevents rain splash
- all parts of the plant above the soil surface slow down runoff and enforce accumulation of eroded soil
- subsurface parts of the plant improve organic matter content of the top soil and thus improve soil fertility, stabilize the soil, and increase infiltration (= reduction of runoff)

As a rule of thumb, the higher the vegetation cover, the better the protection. However, during heavy rainstorms, high soil losses were observed even under 60 - 85% cover. In addition, if overland flow breaks into the field from upslope areas (runon), rills and gullies may develop despite good cover. In addition, during the on-set of rains after a longer dry spell, vegetative-agronomic SWC may not be efficient. Therefore, vegetative-agronomic measures cannot substitute structural measures completely. A minimum drainage system is always needed.

Attention:

- Be aware that vegetative-agronomic measures may be in competition with crops for light, water and nutrients.

13.2.5 Impacts of selected structural SWC measures

Type	Advantages	Disadvantages	Labor
Fanya Juu	▪ very good erosion control, ▪ drainage remains open during terrace development	▪ yield reduction if not supplemented by agronomic measures ▪ considerable top soil removal below structure; ▪ pest and weed infestation likely; ▪ prone to waterlogging if level structures (along the contour)	highest labor input
Soil / Stone Bund	▪ very good erosion control	▪ drainage may be blocked during terrace development ▪ considerable top soil removal below structure; ▪ pest and weed infestation likely; ▪ prone to waterlogging if contour structures	lower labor input
Grass Strip	▪ fairly good erosion control ▪ less prone to waterlogging	▪ weed infestation ▪ harbor of rodents	lowest labor input

13.2.6 Spacing of SWC measures

Optimal spacing from a technical point of view can be obtained from available SWC guidelines. However, narrow spacing has often been unacceptable for farmers because it reduces the cropping area considerably and it hampers farm operations. Let farmers determine the minimum spacing acceptable for them and try to implement additional vegetative-agronomic measures if the spacing seems too wide from a technical point of view. Consider other needs of the land users who may be incorporated into the SWC system (e.g. hedge rows or tree rows in case of fuel and construction wood shortage).

13.2.7 Planning of SWC interventions

- Vegetative-agronomic SWC has to be given priority. It is considered to be protective and at the same time productive. However, climatic limitations may prevent sufficient cover to be developed in time when intensive rains start. This is usually during the on-set of the rainy season. In this case, vegetative SWC needs to be supported by
- Structural SWC measures that control drainage. This is not only necessary during the on-set of the rains, but also during high erosivity rainfall at high plant cover. Thus, efficient SWC contains both vegetative-agronomic and structural components.

- In case that even a combination of both SWC components is most likely not efficient, land use change is the only remaining alternative. Changes take place from cropland to pasture land to woodland.

13.2.8 Impact assessment of SWC

SWC is an integral part of sustainable land management, which means a compromise, in the long run, between farm productivity, income security, protection of resources, and viability and acceptability of measures. If only one of the five aspects is not included, the land management will not be sustainable on the long run. Select criteria or indicators how to evaluate the performance of SWC measures from the beginning in a participatory manner together with the land users and other stakeholders concerned. You need to identify at least one indicator out of each group:

Sustainability dimension	**Example indicators**
Economic	crop yield, variability of crop yield, fodder production, wood production, food supply on the market, cost-benefit ratio, use of fertilizers, pesticides, herbicides
Social	food security, land security, adaptation of SWC by the farmers
Ecological	soil loss, runoff, ground cover, water quality on-site and off-site

13.3 Questions and issues for debate

- Why do you need a DSS tool in the framework of research undertakings that are meant to solve problems identified by researchers?
- What is the functional relationship between IMA and DSS? Elaborate on the tools common to both.
- Design a hypothetical land resources innovation and discuss on how you intend to introduce it to a community of farmers in a semi-arid environment.

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Annex 1 Brief Description of the Research Sites in Ethiopia

A1.1 Maybar

The Maybar catchment, comprising 112.8 ha of hydrological catchment is located at 39°40’ E; 11°00’ N in South Wello, Amhara Region; 14 km SSE of Dessie with an altitudinal range from 2530-2858 m a.s.l.

Climate and agro-ecological classification

Maybar is located in the Moist Weyna Dega /Moist Dega agro-climatic zones. According to Thorthwaite it is classified as sub-humid climatic zone with mean annual temperature of 16.4° C, mean annual rainfall of 1211 mm and a growing period of 175 days. The standardized climate diagram for Maybar in Figure A1 shows a bimodal rainfall regime with one dryer month (June) between *belg* (small rainy season) and *kremt* (main rainy season). During 5 months (April to May and July to September), mean monthly rainfall exceeds 100 mm. November and June show arid conditions.

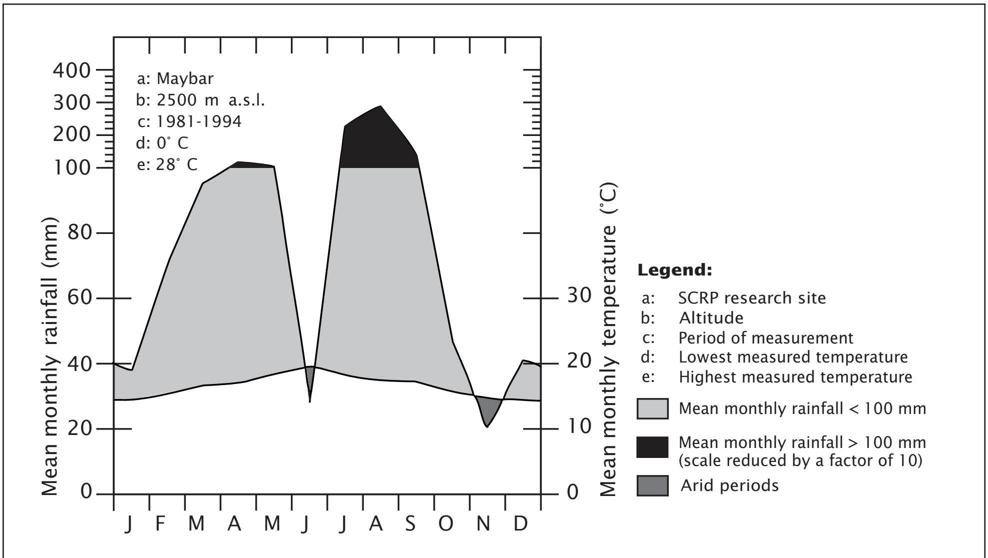

Figure A1: Climate diagram for Maybar

Geology and soils

The Maybar catchment is situated on volcanic Trap series, mainly consisting of alkali-olivine basalts. Soil genesis and properties are mostly influenced and defined by topography, soil erosion features, and accumulation surfaces since the geological formation and thereby the parent material for the soils developed is assumed uniform through out the catchment. More than 50% of the catchment land area is covered by shallow Phaeozems, associated with Lithosols, i.e. extremely shallow to shallow (soil depth 0-50 cm, with an average of about 15 cm), stony dark brown clay loam soils, mostly excessively drained and well structured. Due to limitations in moisture and nutrient storage capacity these soils are not suited for crop production. Since these soils occur on steep slopes, rooting depth is also limited. Severe erosion hazard also limits these soils from being used for crop production. The moderately deep to deep Haplic Phaeozems, covering one fifth of the catchment area are dark brown, stony clay loam soils. They have well developed structure are generally well drained occurring mainly on concave, moderately steep slopes covered in some places by natural woodland or remnant forest, even on steep slopes. These soils are used for intensive crop production.

The colluvial and alluvial accumulation surfaces on less steep slopes and outer parts of the valley bottoms are characterized by deep Haplic Phaeozems covering about 7% of the area. These dark brown, sometimes grayish dark brown, stony clay loam soils have a moderate, in flatter areas even imperfect drainage. This can cause problems for crop production during wet seasons. In some places, these soils, which used to have a high agricultural potential are now showing severe signs of degradation in terms of loss in organic matter and soil fertility decline. Due to their physiographic position, crop cultivation on these soils suffers from periodic flooding. Hydromorphic soils also occur in the central part of Maybar occupying the valley bottoms. The Mollic Gleysols have a very high water table and are often water logged and swampy. A sub-division into two types of these soils is essential from the soils management point of view. Those Molic Gleysols with a water table rising to within 20 cm of the soil surface during the rainy season are not suitable for crop cultivation. The second types are soils with a water table within 20-50 cm below the surface and are used for crop production in many places. Farmers, however complain from periodic waterlogging encountered even when they construct small drainage ditches. Fluvisols and Regosols cover only 1% of the entire catchment land area.

Farming systems and socioeconomic setting

The people of the Maybar catchment exercise a rain-fed, subsistence oriented mixed crop-livestock production farming system with ox drawn farm implements. The major crops are tef, wheat, barley, pulses and maize. The climax vegetation in the area is dominantly coniferous forest with *Juniperus procera* and *Podocarpus glacilior*.

The population consists of Amhara people with a major religion of Islam. Religious authority, and associations are traditionally highly respected and powerful in the community. The management of common properties and communal socio-economic activities are also in the hands of the religious leaders. The local political affairs including land administration are undertaken through the Peasant Association. After the land proclamation of 1975, which provided land to the tiller by distributing land to resident members of the Peasant Association, land became the State property. The 1995 Ethiopian constitution placed land in the hands of the State governments and provides the land users to inherit the land to their kin, lease it for long term arrangements and enter also into other forms of land transaction but not sell it as a commodity or hold it as a collateral for loans and credits.

The land holding varies from 0.5 to 1.0 ha depending on family size. Common holdings are managed and used collectively. Smallholdings coupled with low yields make it difficult for a family to subsist. In the early 80's more than half of the catchment was used for grazing. In 1984, area exclosure was introduced in Maybar in order to protect marginal land from anthropogenic induced interference and further degradation. After that, drastic reduction of sediment load was observed and measured in the catchment. In general, the situation in Maybar is characterized by poverty. Population pressure is high. Individual landholdings are very small and yield per unit area is low. Fallow periods have been shortened to almost nothing (Lötscher, 2003; Belay, 2000).

Farm animals are important in Maybar. Oxen are needed for plowing and along with cows, heifers, bulls, mules, horses and donkeys for threshing crops. Mules, horses and donkeys transport goods and people. Small ruminants are raised mainly for sale to supplement income from crop production. Farm animals are also considered as assets in case of crop failures or for sale when cash is needed for other social activities. Only a few farmers (20%) own a balanced combination of species such as a pair of oxen, one cow, a heifer, a donkey, a mule or a horse, a few sheep, and a few other animals. The majority of the families (60%) own only few animals, for example one ox, one cow, one heifer, one donkey, and a few sheep. The rest of the families (about 20%) own either very few animals – mainly one ox or one cow, a donkey, and a few sheep – or none at all. Since there is an acute shortage of fodder in the area crop residue is the main component of animal feed. All crops are harvested close to the ground to collect as much fodder as possible. Use of commercial fertilizers is very limited because of high cost and using compost and manures is minimal owing to the difficulties of transporting in masse (Lötscher, 2003).

A1.2 Hunde Lafto

Hunde Lafto catchment is found in Western Hararghe Zone of the Oromya Region at 40°59' E, 9°07' N, 20 km southeast of Asbe Teferi. The hydrological catchment covers 236.4 ha at an altitudinal range from 1963-2315 m a.s.l.

Climate and agro-ecological classification

Hunde Lafto is located in the dry to moist Weyna Dega agroclimatic zone. According to Thorthwaite it is classified as sub-humid with an annual mean rainfall of 860 mm, mean temperature of 18.3° C and a growing period of 135 days. Figure A2 shows the standardized climatic diagram for Hunde Lafto. A bimodal rainfall regime with one drier month (June) between *belg* (small rainy season) and *kremt* (main rainy season) characterizes the area. For five months altogether (April to May and July to September) mean monthly rainfall exceeds 100 mm. Conditions from October to February are arid. The index of aridity according to de Martonne and Lauer for these five months is below 20 (SCRP, 2000). In the figure the rainfall curve drops below the temperature curve.

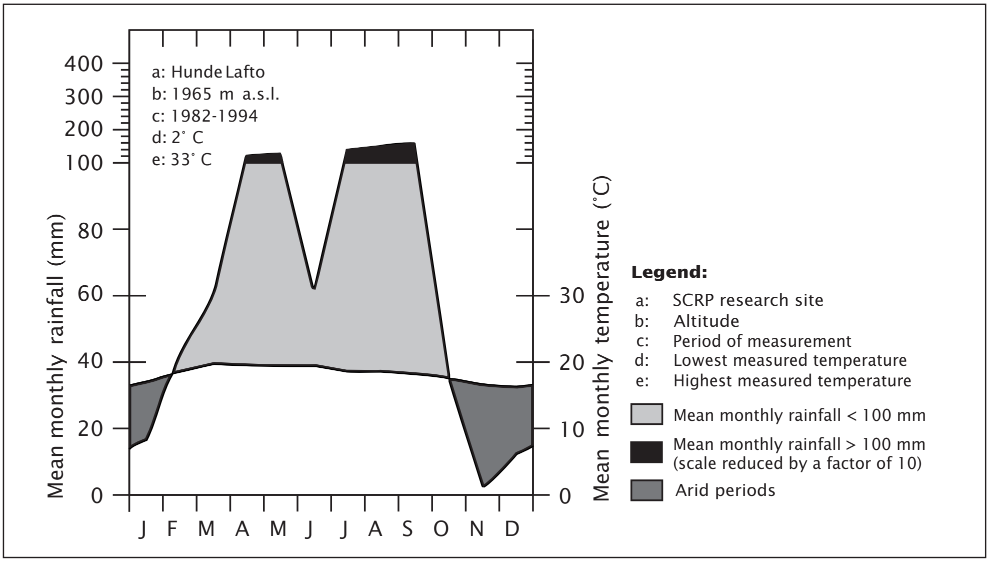

Figure A2: Climate diagram for Hunde Lafto

Geology and soils

The vertical rock formations in the catchment are, from bottom to the top: Pre-Cambe-rian basement complex, Mesozoic sediments (Adigrat sandstones, Antalo limestones, and upper sandstone), and Cenozoic trappean lavas (Mohr, 1971). The trappean lavas are composed predominantly of alkaline olivine basalts, tuffs, rhyolites, and phyroclastic fragments all belonging to what is generally described as the Ashangi Groups (Merla et al., 1979). Most of them have definite alkaline properties and may account for the neutral to slightly alkaline reaction of the soils occurring in the study catchment. Relief rises 356 meters, from 1965 m a.s.l. at the outlet of the catchment to 2321 m a.s.l. on the top of the mountain peak. Striking elements of the terrain are 1) interfluves whose shapes are convex, concave, or linear, some of the interfluves also have terrace like broad steps; 2) V-shaped valleys with their steep walls which deeply dissect the landscape between the interfluves, and 3) ridges and hills forming the northwestern, the northern and the northeastern limits / divides of the catchment. Surface slopes can be as gentle as 1%, and as steep as over 173% (60°) on stream banks. Nevertheless, most of the catchment is hilly and mountainous.

Soil genesis has been mainly influenced by topography and anthropogenic interventions. Geology is only partly responsible for soil type differences and soil development. In the catchment area volcanic rocks of the Trapp series predominate (tertiary effusive, mostly basic layers). Terraces and flatter parts of the catchment are situated on softer rocks like tuffs, steeper parts are compact basaltic rocks. In the southeastern part of the catchment there are small amounts of mesozoic (cretaceous) limestone while in the eastern part an area of cretaceous quartz-sandstone can be found.

Vertisols occur through out the whole area on flat to moderately steep slopes (mostly below 14%). All Vertisols show high stone content and swell-shrink characteristics. This leads to three different problems: 1) The high clay content (40-80%) combined with a low sand content is responsible for a high amount of water retained in fine pores, and relatively low amount of available water. 2) The swelling and shrinking lead to serious problems in soil management. 3) Swelling and shrinking also lead to an upward moving of stones. The third fact is not necessarily a problem, though, because of the resulting better protection against splash erosion and the increase in soil cover, which reduces evaporation as also observed in similar other places in Ethiopia (Nyssen et al., 2001).

Cambisols are concentrated in the southeastern part of the catchment. The water holding capacity of these soils is generally lower than in Vertisols because of lesser soil depth. Other chemical and physical properties are sufficient to good. Fluvisols occur in the valley floors and are usually very deep (>120 cm). These soils are well drained and in general have favorable physical soil properties for crop production. Phaeozems are mapped as transitional soils between Rankers and Cambisols; partly they have a weak development of B-horizon. Most of them have a low effective water storage capacity and are shallower to moderately deep. The high stone content (partly strongly weathered) nevertheless constitutes a sufficient reservoir for releasing plant nutrients. On steep slopes Rankers and Lithosols are found exhibiting high gravel and stone content limiting their water holding capacity. The areas of quartz-sandstone are covered with Regosols. These soils are seriously affected by erosion with visible signs of degradation making them the least favorable soils for crop production.

According to Thomas (1991), nearly 39% of the catchment area is covered with shallow to very shallow soils (0-50 cm). Another 47% is covered with soils having considerable to sufficient depth and 14% of the catchment is covered with deep to very deep soils. Most soils (except Lithosols and Regosols) have medium to high nutrient levels with a base saturation of >90%, where the major part of the exchange complex is dominantly occupied by calcium. The only limiting factor is very low available phosphorus.

Farming systems and socioeconomic setting

The Hunde Lafto catchment belongs to the Wabe Shebele river basin. It is considered a typical representative of the central basalt mountain section of the Eastern Highlands, which due to their suitable climate and fertile soils are preferred for settlements. Most of the population in the catchment belong to the Oromo ethnic group and are mainly Moslems. A few Amharas with Orthodox Christian faith have also settled in the area (Wogayehu and Drake, 2002; SCRP, 2000). The farming system evolved as subsistence crop-livestock complex where ox-drawn implements and the *dengora* cultivation are also exercised. Both *Belg* and *Kremt* crops are cultivated as rainfed crops. Irrigation is not exercised in the catchment. A variety of crops are grown including: sorghum, maize, tef, barely, wheat, peas, beans, haricot beans (*Phaseoulus vulgaris*), lentils, linseed, sweet potato (*Ipomea batatas*), chat (*Chata edulus* and coffee (*Coffee arabica*). The crops are planted mainly as intercrops with sorghum, maize and haricot beans. Barley, tef, and wheat are mostly grown as monocrops. The intercrops occupy the larger land areas out of the total cultivated land (41%). The non-cultivated area (59%), on the basis of dominant plants, can be divided into grassland (51.7%), bush land (28.8%), shrub and woodland (12.7%), and fallow land (6.8%). The different plants (grass, bush, trees) do not grow in isolation but in varying combinations. From this land use it is very clear livestock are important in the catchment. Traditionally cattle represent a central element in the farming system of the Chercher highlands. If possible, more cattle are held than actually needed for traction, so as to be able to sell products or to cover the needs of households. Elaborate feeding practices of cut-and-carry system combined with field tethering of animals is exercised in the area making it appropriate not only for sustained integration of livestock into conservation practices by restricting free grazing but also fattening livestock for sell in accordance to market demand for meat. However, recurrent drought has threatened the management of cattle and as a consequence the people in the catchment have fewer number of oxen for plowing. According to a study made in the 80s (SCRP, 2000) and the 90s (Wogayehu and Drake, 2002) out of the whole population in the catchment 71% did not own a pair of oxen. This significantly reduces the possibility of proper and timely management of the cultivated fields. It also makes poorer households more dependent on better-endowed farmers to lease their land or enter into a sharecropping arrangement.

The land tenure policy elaborated for Maybar is operative also for Hunde Lafto. However since the last land distribution in the area, the land holding size ranges between 0.2 and 3.1 ha. Only a few households own more than 2 ha, and overwhelming majority (74%) own less than 1 ha. According to Wogayehu and Drake (2002) the present land tenure arrangement has not led to redistribution of land in the last decade where the farmers asserted that land insecurity is no more an impediment to investment for soil and water conservation activities at farm and community levels. The natural vegetation has almost disappeared because of deforestation and overgrazing. However, the remaining species of trees like *Podocarpus glaciors*, *Juniperus procera*, *Acacia abyssinica* and *Olea africana* bear witness to the original forest cover.

A1.3 Andit Tid

The Andit Tid catchment is located in Amhara region 180 km ENE of Addis Abeba at 39˚43’ E, 9˚48’ N. It comprises of 477.3 ha of hydrological catchment with an altitudinal range from 3040-3548 m a.s.l.

Climate and agro-ecological classification

Andit Tid is found in the Wet Dega and Wet High Dega agro-climatic zones. According to Thornthwaite it is classified as humid with mean annual temperature of 12.6˚ C, mean annual rainfall of 1417 mm and a growing period of 175 days. A bimodal type of rainfall regime characterizes the area with one dryer month (June) between *Belg* and *Kremt* (Figure A3). During four months (May and July to September) mean monthly rainfall exceeds 100mm. The months from November to February show arid conditions. The index of aridity for these months is below 20 (SCRP, 2000). In the standardized climatic diagram, the rainfall graph drops below the temperature graph.

Geology and soils

The eastern part of the catchment includes the escarpment that separates the watersheds of the Abay and the Awash river basins. The area can be considered as an inclined plain with its highest peak in the southeast (3560m a.s.l.) and its lowest elevations in the northwest (3040m) and southwest (3060m) respectively. It is divided into four valleys running from southwest to southeast. Most of its watercourses are perennial with variation in run-off volumes according to the annual rainfall, which

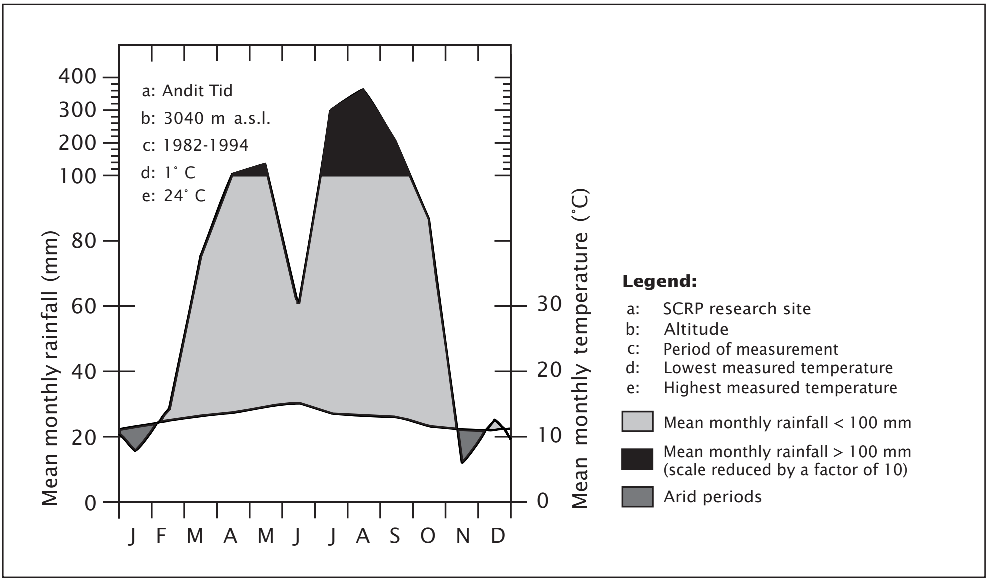

Figure A3: Climate diagram for Andit Tid

is concentrated in the two rainy seasons. A few springs are found in the catchment with variable yield of water. The geology of the area is characterized by volcanic rocks (most of them acidic) of the Magdala group (upper Miocene-Pleistocene) with rhyolites, trachytes, rhyolitic and trachytic tuffs and basalts. The local petrography is highly variable within short distances.

The most important soils in terms of extent and quality are Andosols occurring either as Humic or Ochric. Both are found between approximately 3000 and 3550m a.s.l. but it seems that the Humic Andosols occur in slightly higher positions and on steeper slopes. On top of ridges and on very steep slopes, these soils are shallow and contain high volume of stones (stony phase). Ochric Andosols have most probably developed through intensive cultivation for agricultural use coupled with soil erosion that removed the organic matter content of the topsoil from Humic Andosols. The occurrence of Ochric Andosols on gentler slopes suggests that these areas were the first ones to be cultivated for crop production, and that these soils, through repeated tillage practices slowly degraded from humic into ochric. Except for available phosphorous both soils exhibit high nutrient reserve and better water holding capacity.

The Ochric Andosols have relatively higher clay content, higher pH (5.2-6.2) as compared to Humic Andosols (4.9-5.8) and are usually less productive because their organic matter content is much lower. In some of the Humic Andosols the highest content of organic matter found was 19.6% but in general the content was twice as high as that found in the Ochric Andosols. The physical and chemical properties of these soils provide good conditions for crop production. The valley bottomland units are covered by Fluvisols that had developed through the accumulation and deposition of eroded soil material from the surrounding areas. Soil depth on relatively flatter slopes can reach more than two meters. The physiochemical properties of these soils are influenced by their origin from the surrounding area. Despite smaller pore volume as compared to the Andosols, the Fluvisols have a higher water holding capacity. The organic matter content of the topsoil is lower than the in most Andosols but increases slightly with depth. This confirms that these Fluvisols have been developed from the depositional material originating from up-slope eroding soils. Nutrient content is relatively good but deficient in available phosphorus.

Lithosols occur on steep slopes and as a result of continued soil erosion, have a high surface stone cover thereby limiting plowing by oxen. The water holding capacity is about 60-80 mm, a mean pH level of 5.9 and a mean organic matter content of 4.9%. The available phosphorus level is relatively higher in the Lithosols as compared to the other soils. Regosols are strongly influenced by erosion and accumulation and the profiles are usually not deeper than 50-60 cm. where the underlying rock is weathered making tillage practices possible even on the shallowest soils. These soils have the lowest organic matter content (in general <1%), are slightly acidic and the amount of plant available water is very low owing to the shallower depth. The available K^+, exchangeable Mg^{++} and available phosphorus are remarkably low.

In the lower and most western parts of the catchment Regosolic Cambisols can reach to a depth of 80 cm. They developed from accumulations from landslides and materials eroded from the Andosols. Plant available nutrient content is higher with slightly acidic pH. Deep gullies are found on almost all steep slopes especially in the lower parts of the catchment. This is a consequence of climatic conditions, properties of the soils and more importantly to human activities that have been degrading the land resources for centuries.

Farming systems and socioeconomic setting

The farming system of the Andit Tid area is characterized by small-scale subsistence crop-livestock mixed production where the major crops are barley, wheat, peas, beans, linseed and lentils cultivated with ox-drawn implements. Sheep, goats, cattle, horses, donkeys and chicken are reared in an open uncontrolled grazing system. The natural vegetation is highly degraded but remnant trees of *Juniperus procera* and *Podocarpus gracilior* are observed at the lower parts of the catchment whereas *Erica arborea* are dominantly occurring on higher altitudes of the catchment. Currently *Eucalyptus globlus* is being planted as a reforestation program in gullies, along riverbanks, on private and communal lands.

Because of the high risk of frost during the *Belg* season, barley is cultivated as the staple crop in the upper part of the landscape. During the *Kremt* season mainly the lower parts are cultivated, leaving the Belg fields fallow for a long period of time, which later on are burned as part of the land management system for the area called *guie*. Depending on the area, cultivation seems to have started 530 to 1140 years ago (SCRP, 2000). The present population is entirely Amhara practicing the Orthodox Christian faith. The land reform of 1975 brought new land redistribution where each household was allocated land for cultivation. Since then land holdings have been reallocated and split up due to the growing number of families entitled to land. This fragmentation of land is alleged to have caused a sense of insecurity for investment on land (Bekele and Holden, 1998, 1996) in previous times but the recent introduction of land registration, titling and certification in the country will create a sense of security on the land holdings for investment. According to Yohannes (1999, 1998) the land holding varied dependent on the wealth of the individuals. However, the average holding were about 2.95 ha per household where 41% of the households owned less than 2 ha, 55% had 2-5 ha and only 4% had larger holdings.

Livestock play important role in the farming system by providing traction, transport and as a source of cash. Sheep are the dominant species constituting 55% of the animals followed by cattle (19%) and goats (12%). The remaining constitutes the equines. Currently 26.5%, 15.3% and 56.5% of the smallholder farmers in the catchment own 0,1 and 2 oxen respectively. Crop residue is used as animal fodder. Oxen are used for traction whereas sheep and goats are sold for cash to complement household consumption and crop production activities. Animal manure is used for maintaining soil fertility and as a source of fuel. No commercial fertilizer is used as an external input to enhance soil fertility and improve yield of crops.

A1.4 Anjeni

Anjeni is found in Dembecha, Amhara region, northwest of Addis Abeba located at 37˚31’ E, 10˚40’ N. The area is relatively densely populated with approximate density of 125 persons per square km (Gette, 2000).

Climate and agroecological classification

The area of Anjeni is contained within the agro-climatic profile of Mt. Choke at an altitude of 2405 to 2500 m a.s.l. lying at the transition zone of Weyna Dega and Dega agro-ecological zones. It shows the characteristics of a Wet Weyna Dega zone with a unimodal rainfall regime with five months during which rainfall exceeds 100 mm (Figure A4). The months from November to March show arid conditions with an aridity index according to Martonne and Lauer (SCRP, 2000) for these months is below 20.

The climate according to Thornthwaite is sub-humid characterized by a pronounced rainy season between May and October with a mean annual rainfall of about 1690 mm, mean annual temperature of 16˚ C and a growing period of 242 days. The long-term mean annual minimum and maximum temperatures of the area are 9.03 and 23.3˚ C, respectively. The mean monthly minimum and maximum temperature range between 6.2 and 26.1˚ C with a lowest recorded temperature of 0˚ C and the highest has reached 33˚ C (Gette, 2000; Bosshart, 1997c).

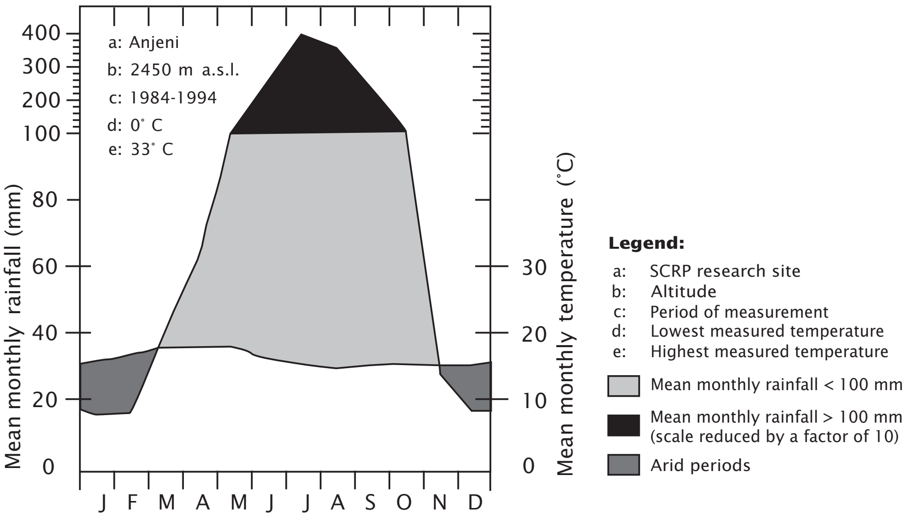

Figure A4: Climate diagram for Anjeni

Geology and soils

The geological formation of the catchment area belongs to the basaltic Trapp series of the Tertiary volcanic eruptions and is similar to most parts of the central highlands of Ethiopia (Gette, 2000). The topography of the area is typical of Tertiary volcanic landscapes deeply incised by streams, resulting in the current diversity of landforms. The genesis of the soils is then from the volcanic and reworked material and rarely from sedimentation processes. According to Gette (2000), the soils of Anjeni vary within a short distance resulting in eight major soil units and ten sub-groups. Alisols cover 41% of the total land area of the catchment occupying the valley floors and the depressions of the foothill land units. The gently sloping, convex to linear land units are covered by the medium deep Nitosols amounting to 23.8% of the land cover. The steepest land units are convex shaped and covered by the Regosols and Leptosols (12.4%) which are shallow in depth that are assumed to be derived from the truncation of the Nitosols in the process of degradation by soil erosion. The hilltop of the catchment and partially the medium steep sloped land units are covered with moderately deep Dystric Cambisols (19%). Pockets of Luvisols, Lixisols and Acrisols are also found on different land units in the catchment.

The soils of the catchment are generally acidic and low in organic matter; have low to medium total nitrogen and available phosphorus. The cation exchange capacity of these soils is high probably related to the high clay content. The wide coverage of the relatively shallow Cambisols and the very shallow Regosols and Leptosols is a clear indication of the land degradation processes going-on in the area.

Farming systems and socioeconomic setting

The Anjeni catchment is located in the upper part of the Wet Weyna Dega and is typical representative of the intensively cultivated area in Gojam. The traditional farming system of land use was adapted to a natural environment with low population and livestock densities. It was characterized by long fallow periods, reliance on natural vegetation and minimal pressure on grazing land. However, increasing human and livestock population has put tremendous pressure on the land, that land degradation processes are clearly observed (Gette, 2000). The study by Gette (2000) shows that the total population and population density of the Anjeni area increased by 185% and 43.85 persons per km^2 in 1957 to 125.26 persons per km^2 in 1995. The same study also show that the natural forest cover decreased from 27.1% in 1957 to 0.3% in 1995. On the other hand, cultivated land increased from 39.4% in 1957 to 77% in 1995, particularly of interest here is that the push for cultivated land into grazing, bush land and marginal lands is increasing. This is explained by the increase in cultivation of steep slopes (from 19.4% in 1957 to 79.5% in 1995).

The population of Anjeni is Amhara who are adherents of the Orthodox Christian faith where church and religious beliefs have a considerable influence on farm activities. Numerous holidays, some with strict rules are an integral part of the agricultural calendar that may interfere with the organization of soil and water conservation works. The farming system in Anjeni features both the up-land cereal based system and the smallholder mixed system of agriculture (Ludi, 1997). Crop production and livestock rearing are closely linked in Anjeni but not well integrated into the farming system. Trees that produce fruit and fodder, vegetables and tubers are completely lacking. The main emphasis in farming is clearly on cereals, pulses and oil seeds. Mixed cropping is only found around homesteads only where maize, potatoes and rapeseed are produced. All other crops are planted as monoculture. There is no agroforestry with the exception of planting rows of Gesho in homestead gardens surrounded by Eucalyptus (Ludi, 1997). Plowing is done with ox-drawn implements.

Livestock play an important role in the land use system as a source of production, food, income security and symbol of status. Providing fodder for livestock is one of the major problems encountered by the inhabitants of the area limiting the desire to have more cattle since the extent of the grazing lands has decreased substantially whereas the population of livestock increased tremendously (Ludi,1997). One of the problems that prevent poor households from becoming food self-sufficient is the lack of oxen for plowing their land since 28.4% of the population is not having a pair of oxen. The remaining has one pair (52.6%) or more oxen (19%).

A1.5 Gununo

The Gununo research station with a hydrological area of 166.8 ha, divided into a treated and non-treated sub-catchments, is situated at an altitudinal range between 1982 and 2103 m a.s.l. It is found in Wolayta in the Southern Nations Nationalities and Peoples region, 16 km NNW of Sodo at 37°38’ E and 6°56’ N. The topography is characterized by undulating plateau marked by a series of V-shaped valleys that accommodate only seasonal and intermittent streams. The interfluves, which are generally level at the crests, assume considerable gradients in their middle and lower slopes. Very steep slopes occur along the valley sides where slopes greater than 30% are very common (Belay, 1992).

Climate and agroecological classification

Gununo is located in the Wet Weyna Dega agro-climatic zone and according to Thornthwaite it is classified as humid with mean annual temperature of 18.8° C, mean annual rainfall of 1341 mm with a growing period of 284 days. The standardized climatic diagram (Figure A5) for Gununo shows a slightly bimodal rainfall regime. In some years, *Belg* and *Kremt* are separated from each other through one drier month (June), while in the other years only one rainy season is manifested. For nine months (February to October) mean monthly rainfall exceeds 100mm. The index of aridity for the three months from November to January showed arid conditions.

Geology and soils

The geology of the whole Wolayta plateau is made up of volcanic rocks of the Magdala group consisting of ignimbrites, rhyolites, trachytes and trachytic and rhyolitic tuffs of the Miocene and Pleistocene periods. Rock exposures at a number of sites along river valleys in the area show weathered ignimbrites and trachytes. In most parts the parent rocks have developed very deep soil and weathered regolith, which in some areas extend to depths of more than ten meters (Belay, 1992). Nitosols are the dominant soils covering around two third of the land area. These soils are very deep,

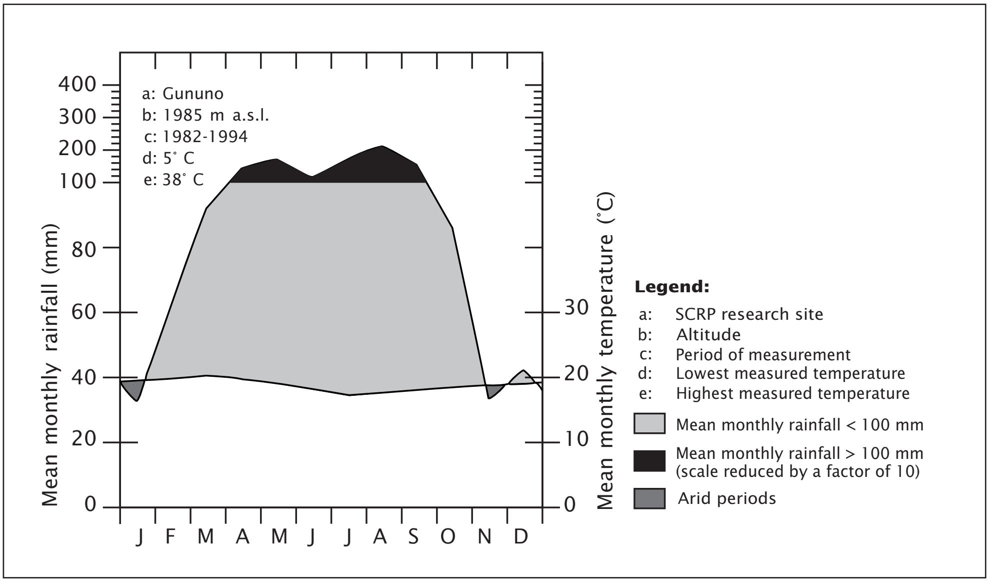

Figure A5: Climate diagram for Gununo

characterized by a clay content that increases rapidly with depth. The soils are well drained with a high moisture holding capacity. They are deficient in nitrogen and available phosphorus and have low base saturation particularly exhibit low level of exchangeable calcium. These soils are seriously affected by soil erosion, not because of high erodibility (the erodibility factor is about 0.1) but because of intensive land use (Belay, 1992).

Humic Acrisols occur on flat to gently sloping land units. The physiochemical properties are similar with that of the Nitosols. The extremely low content of available phosphorus and nitrogen and the low base saturation constitute a limitation for crop production (SCRP, 2000; Belay, 1992), hence large parts of the Acrisols are covered with grass and are used as grazing lands. The erodibility factor is a little higher than the Acrisols (about 0.16). Phaeozems associated with Lithosols cover the steep slopes of the escarpment in the western part of the catchment. On terraces below or within the escarpment the Phaeozems are associated with Nitosols. Soils of the terraces show a strong colluvial deposition, are frequently flooded and therefore have better chemical properties. Soil erosion and accumulation are the dominant processes on these soils. The erodibility factor of these soils lies between 0.2 and 0.22 (Belay, 1992). Fluvisols and Gleysols with erodibility factor of 0.25 and 0.31 respectively occur along the riverbeds and are not used for crop cultivation.

Farming systems and socioeconomic setting

The people in the catchments belong to the Wolayta ethnic group, the area is one of the most densely populated areas of the country estimated at 523 people / km2 with an average per landholding of 0.63 ha (Belay, 1992). The farming system is a rain-fed subsistence oriented mixed crop-livestock production system with ox-drawn implements. Although agriculture is the main stay of the economy of the area, some people derive additional income from basket making, pottery and petty trading. It is estimated that arable farming and pasture account for 72% and 15% of the land respectively (Eyasu, 2000; Belay, 1992). The portion of land under forests is very small and even here only a few stands of indigenous tree such as *Cordia abyssinica (Wanza)*, *Croton macrostachus (Bisana)* and *Podocarpus graciliros (Zigba)* are observed (Belay, 1992). A widespread plantation of Eucalyptus, which is an exotic fast growing species, is being practiced by communities and individuals (Eyasu, 1998; Belay 1992).

According to Belay (1992), almost every farmer practices two cropping systems on the cultivated land-a garden and field system. The gardens are kept very close to the homesteads while the field cropping is practiced far away. In the garden the farmer adds a lot of stable yard manure and cultivates highly valued perennial crops, such as coffee (*Coffe arabica*) inset (*Inset ventricosum*), *different spices, and a variety of vegetables* (Eyasu, 2000). On fields far from the homesteads farmers cultivate annual cereal crops, such as maize, sorghum, barley, and tef; legumes (haricot beans) and root crops. The most important tuber and root crops are Irish potato (*Solanum tuberusum*), sweet potato (*Ipomea batatas*), taro (*Colocasia esculenta*) and a variety of Yams (*Dioscorea spp.*). External inputs in the form of fertilizers are practiced although not sufficient enough to bring tremendous yield increases (Eyasu, 2000; Eyasuand Scoons, 1999). Farmers practice intercropping, relay cropping, crop rotations and fallowing to improve soil fertility.

Because of intensive cultivation livestock holdings do not play a prominent role in the catchment. As farmer-traders, families keep livestock such as cattle, sheep, horses, mules and donkeys. Butter is sold as source of cash in addition to the sell of live cattle and beef. However, 20% of the families have no animals at all, and a high proportion (52%) own only 1-3 animals (SCRP, 2000). Although oxen are used for plowing the land their number is low. The majority of the households (95%) do not own a pair of oxen. Poverty and shortage of grazing land is attributed to such lack of draft animals (Eyasu, 2000; SCRP, 2000). In the absence of sufficient draft power farmers are obliged to enter into mutual agreements of sharecropping, sharing of oxen and human labor.

A1.6 Dizi

The Dizi catchment with a hydrological area of 672.7 ha is located in Oromia region constituting part of the western highlands. It is situated 5 and 600 km from the zonal capital of Metu and from Adis Abeba respectively at 35°36' E, 8°22'N.

Climate and agroecological classification

The climatic information is extracted from the review of the area by Solomon (1994) and SCRP (2000) report. Dizi is located in the Wet Weyna Dega agro-climatic zone and according to Thorntwaite it is found within the humid climatic zone having a mean annual temperature of 21° C, mean annual rainfall of 1512 mm and a length of growing period of 245 days. The standardized climatic pattern of Dizi (Figure A6) indicates a uni-modal rainfall regime with seven months exceeding 100 mm. The condition during the months of November to February is arid; the deMartonne and Lauer (SCRP, 2000) index of aridity of these four months is below 20. In the Walter diagram the, the rainfall graph drops below the temperature graph.

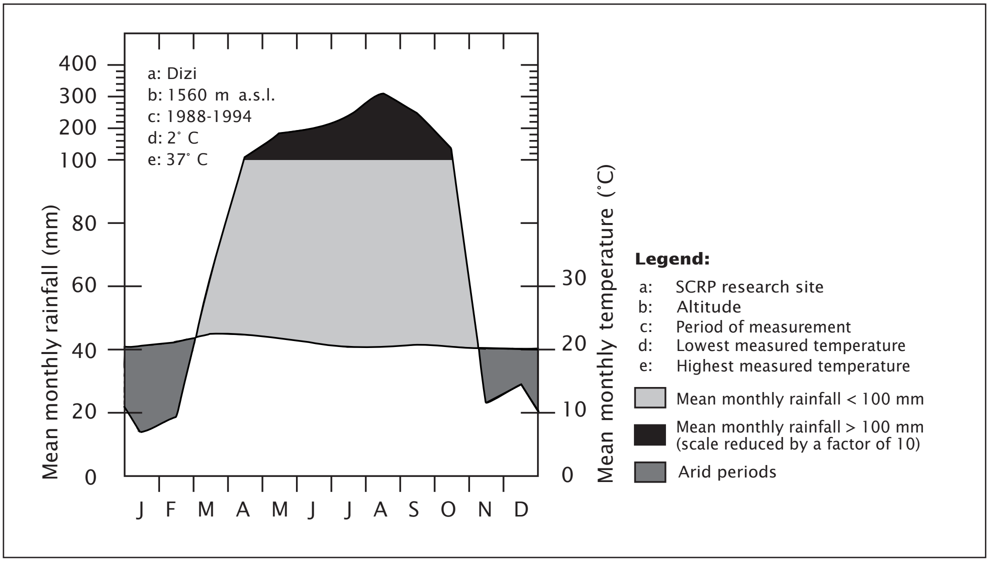

Figure A6: Climate diagram for Dizi

The months with least rainfall are December, January and February, which receive less than 5% of the annual total. Nearly 50% of the rainfall is concentrated between June and August, 20% between March and May and the remaining 25% falls between September and November. The months of March to August when the rainfall is concentrated (70% of annual total rainfall) are the months where agricultural activities such as plowing, sowing, harrowing and weeding are undertaken. As these activities loosen the soil and the vegetative cover is low, the concentration of rainfall during these months is significant in understanding the processes of soil erosion and land degradation (Solomon, 1994). Rainfall variation shows a high of 2385 mm in 1985 and low of 1297 mm in 1990 for an observation of nine years (1982-1990). This variation is note worthy as it can have important implications for processes of soil erosion. Figure A7 shows the total rainfall, erosive rain and erosivity for the period from June 1988 to December 1990 (erosive rain is defined as rainfall greater than 12.5 mm in a given storm). The graph shows that the proportion of erosive rain and erosivity are related to the amount of rainfall, and significantly to the distribution of rainfall over the year. Despite the same amount of rainfall between 1988 and 1989, the concentration of rainfall in 1988 in only half of the year was the reason for the higher proportion of erosive rain and consequently higher erosivity in the same period.

Geology and soils

The Precamberian basement complex dominates the geology of the area. It consists of rocks like the highly metamorphosed Alghe Group Gneisses. They are coarse-grained biotite and horneblende gneisses, which are very hard and almost impermeable. In some locations the gneisses have been intruded by veins of quartz and feldspars, in other places the appearance is more of granite-gneisses (Merla et. al., 1979). Fresh rocks are hardly visible on the surface. A highly weathered regolith layer of up to more than ten meter thick overlies them. The altitude varies between 1565-1789 m a.s.l. with a rugged topography. V-shaped valleys dissect narrow interfluves with moderate to very steep linear and convex slopes. Some of the valley bottoms in between the numerous hilltops are filled with alluvial sediments forming 5 to 100m wide flood plains. In the rainy season these valley floors act as swamps.

According to the study made by Hagmann(1991) there are four major soil units identified in the Dizi catchment. Haplic Lixisols, petric phase, developed in-situ on a weathered regolith layer, are dominant. Lixisols are soils, which, related to the effective cation exchange capacity, have high base saturation. These dark reddish brown soils have dense gravelly layer underlying the organic topsoil. Such gravel layers that are also called „stone lines“ often act as limiting depth for root development and penetration. These soils are very deep, medium textured and well drained. The gravelly layer limits favorable physical conditions. Further limitations are the very low available phosphorus. Although the organic matter content on newly claimed and forestlands is high, it decreases tremendously and rapidly on cultivated lands. Since most of the nutrients are concentrated on the topsoil coupled by the root limiting gravel layer soil erosion severely threatens the fertility of these soils. In association with the Haplic Lixisols, Albic and Gleyic Lixisols, petric phase, occur in smaller area in this land unit. The major morphological features, the chemical properties and limitations are similar to that of the Haplic Lixisols.

The second soil unit, the Fluvic-haplic Lixisols, are soils, which develop on colluvium deposits, the wash material from the adjacent slopes. The profiles, which are relatively deep, show a weakly developed argillic horizon. They exhibit favorable physical properties without any rooting limitations. Chemical conditions are similar to the Haplic Lixisol. Organic matter is however, homogenously distributed with depth. The major soil fertility constraints are low available phosphorus and nitrogen. As the soils are rejuvenated from the wash material from upslope there is sufficient nutrient supply to crops. The high fertility status of these colluvial soils is also indicated by a continuous cultivation period (without any fallowing) for more than ten years on some fields (Solomon, 1994). The land unit of the flat valley bottoms is covered by Gleyic-umbric Fluvisols, which are seasonally flooded and become water logged for an extensive period of time shortening the growing period to around five months per year of the drier season. Alluvial deposits rejuvenate these medium textured soils every year, hence except for low nitrogen, which is affected by the reduced condition of the water logging, the other nutrients are not limiting. The fourth soil unit consists of Lepti-umbric Cambisols, which are of limited extent in the catchment area and have limited importance for cultivation and other agricultural activities. Although these soils are endowed with high content of organic matter on the topsoil, they are shallow to moderately deep with a continuous hard rock.

The influence of cultivation on the soil properties was studied by means of comparison of soils under forest, bush fallow and cultivation (Hagmann, 1991; Solomon, 1994). In this study organic matter content up to 20% was measured under forest cover. This high value, however, drops quickly when land use changes to annual cropping, and vegetation cover is reduced. A drop in organic matter content from the original level to less than 7% was recorded in less than 3 years of continuous cultivation (Figure A8). From this figure it is to be noted that the organic matter content stabilized at around 4-6% on arable land that is continuously cultivated from 4 to 15 years. An organic matter content of this magnitude is considered medium to high for arable crops (Landon, 1991). This is aggravated by soil erosion which amounts to 1 to 2cm per year under cultivation, which is in agreement with other studies elsewhere (Lal, 1995). Topsoil thickness is reduced and the nutrient reserves that are obviously concentrated on the surface layer are lost thereby decreasing the fertility of the soils. The absolute decline in organic matter (related to the reduction of topsoil thickness) was calculated at 86% in some areas (Hagmann, 1991). As the decline in organic matter is more pronounced in the top 0-20 cm (Mwonga and Mochoga, 1989), a decrease in soil thickness through soil erosion after prolonged cultivation on an already shallow soil will result in a drastic decrease in absolute amount of organic matter. The gravelly layer inhibits root penetration especially by annual crops thus restricting rooting to the topsoil on the Haplic Lixisols, petric phase. After 3 to 5 years of cultivation farmers are forced to leave fallow their lands because of drastic decline in yield. The length of the fallow period in the cropping cycle also has an important influence on organic matter content and other properties of the soils in cultivated fields.

The organic matter content increased with the length of the fallow period, and decreased with the length of the cultivation period (Solomon, 1994; Getachew, 1991). These studies show that the rate of restoration was affected by the previous crop-fallow cycles and the type of vegetation established. The restoration under grass fallow (temporarily used for grazing) was less than that under bush cover despite a rest period of the same length. Similarly, despite equally long periods of cultivation, fields with longer previous fallow periods have higher levels of organic matter compared to fields with short previous fallow periods. Studies undertaken elsewhere in Ethiopia show a similar trend (Lemenih, 2004; Zewdu, 2000).

Physical properties of the Lixisols deteriorated under continuous cultivation, while improvements were observed when these were left fallow (Solomon, 1994). Bulk density showed a negative but significant relationship with the length of the fallow period. Similarly, the trend observed in the structure and infiltration rate was towards improvement with longer fallow periods and deterioration with extended cultivation periods. Soil compaction as a result of livestock trampling is also influencing the bulk density of the soils. The bulk density on grazing lands was measured to be 1.34 g/cm^3 which is higher when compared with 0.83, 0.94 and 1.12 g/cm^3 for a coffee forest, un-grazed grass fallow and crop land, respectively. The deterioration of the physical properties of these soils that are put under continuous cultivation and improvements observed with longer fallow periods are closely linked to the organic matter content, since organic matter is reduced under continuous cultivation and improved with increasingly longer fallow periods. The influence of organic matter on the physical properties of soils is an established fact. Therefore management practices that drastically change the organic matter content in this area will definitely reduce the productivity of these lands.

In a study undertaken by Solomon (1994), the yield of maize dropped drastically with a rate of decline around 10% per year (Table A1, Figure A9). The decline continued as the number of years of cultivation increased, but the rate of decline dropped progressively, approaching a steady state of about 35% of the initial level after 12-15 years of continuous cultivation. The high mineralization of organic matter, with concomitant release of organic nitrogen and phosphorus immediately after a forest clearance for cultivation, coupled with the favorable physical soil conditions, is responsible for the observed initial high yield. It was found, however, that organic matter and associated nutrients decreased quickly in the first 3-5 years of continuous cultivation. Soil erosion, although much less compared to other stations, was higher in the cultivated fields as compared with the other land use types (Figure A7). It should be noted though, that soil losses are likely to increase, if deforestation and shortening of fallow periods continue! Nevertheless, organic matter and other nutrients stabilized in a new equilibrium on arable land cultivated for periods between 4-15 years, which is rated medium to high for crop production, while soil erosion continued with cultivation. This clearly shows that decline in productivity is erosion induced in this area.

Hagmann (1991) has pointed out that the major change in physical fertility under continuous cultivation in the form of rooting depth and soil volume is more dominant than the chemical fertility in the long run. With a reduction of rooting depth and soil volume, the absolute amount of plant-available nutrients is low even when nutrient content is relatively high. Therefore, erosion induced productivity loss should be considered as the most serious concern for sustainable land management in these types of soils. Similar studies (Lal, 2005, 1998c; Stocking and Pain, 1983) show that the yields of crops drastically dropped with increasing cumulative soil loss, when effective root depth was shallow.

Farming systems and socioeconomic setting

The socioeconomic situation, historical background, social organization and cropping systems of the area is reviewed by Solomon (1994) and SCRP (2000). The system is characterized as rain-fed subsistence farming with ox-drawn implements. Coffee is produced as cash crop, whereas maize, tef and sorghum are cultivated for subsistence. According to Hassan (1992), and McCann (1995) basically Oromo people live in the area, who migrated from the neighboring areas of Welega around the second half of the 18th century. The Amharas started to settle in the area by the end of the 19th century, when the region was conquered by Menelik ll. Soon afterwards, the area was fully integrated in to the Ethiopian polity and land was redistributed to those involved in the conquest of the region (McCann, 1995).

The redistribution of land effected by the numerous land reform decrees since the 1930s had a considerable impact on land ownership. Non-indigenous persons were permitted to acquire land by purchase. However, most of these new owners did not settle in the area. Instead they remained in their home areas and utilized the land by mainly planting coffee marking the beginning of absentee land-lords (Pausewang, 1983). The 1975 rural land proclamation made land public property and abolished the tenant-landlord relationships. This proclamation and the subsequent constitution of 1995 gave the landless peasants and tenants the right to use the land. Recently land certification is started to insure security and investment on land providing farmers to enter into long term leasing and inheriting their land to their kins. The average holding is nearly 2.6 ha ranging from 1 to 9ha. Approximately 80% of the households had 2-4 ha of land. According to Solomon (1994), nearly one third of the household heads were born elsewhere and migrated into the area between 1940 and 1985, to a large extent as part of the resettlement programs in the 1980s. Twenty percent of the settlers (categorized as short-distance settlers) are from within the zone of Illubabor and the remaining 80% are from outside the region (long-distance settlers) and the area of origin includes Shewa, Gondar, Gojjam and Tigray.

The immigration has contributed to a considerable degree of mixing of the ethnic groups and a great deal of cultural transfer (McCann, 1995; Solomon, 1994). The mixed farming economy based on the ox-drawn implements was a most significant development which tried to lower the dependence on the hoe-culture and shifting cultivation. Previously farmers were clearing patches of forest land for cultivation and after a few years of continuous cultivation, they moved to other places and come back to the abandoned field long after fertility was restored. The introduction of the plow by settlers from the north changed this practice of slash and burn, because better tilling was possible with the plow than with the simple hand tools used earlier. The introduction of cereal crops, notably tef also increased the crop diversity in the area. Maize is the major crop produced in the area, occupying nearly 72% of the cultivated land put under annual crops. Tef and sorghum, which account to 16% and 9% respectively of the total area under annual crops, are also grown along with barley and wheat for subsistence. Root crops such as *Godere* (*Clocasia antiquorum*) and sweet potato, pulses like *Adenguare* (*Vigna unguiculata*) and horse beans are produced around homesteads in the area. Coffee is the major perennial crop in the area and is the most important cash crop by value.

Livestock are an integral part of the farming system with an average of 5.64 farm animals per household of which 85% are cattle. The remainders are sheep and horses, accounting for 13% and 2% of the total farm animals, respectively. Although oxen are the important sources of draft power, 22% of the households do not posses any oxen. 33% have only one ox, 38% have a pair of oxen and less than 7% have more than a pair. This is a serious constraint in farm operations and the problem is attributed to the prevalence of Trypanosomiasis, locally known as *Gendi*. Besides providing the draft power and cash source, livestock are also used as sources of manure for soil fertility maintenance. Farmers in the area apply several soil fertility measures to restore productivity. More than half of the farmers practice crop rotation along with the application of manure and commercial fertilizers. The application of manures is mainly restricted to farms that are nearer to the homesteads.

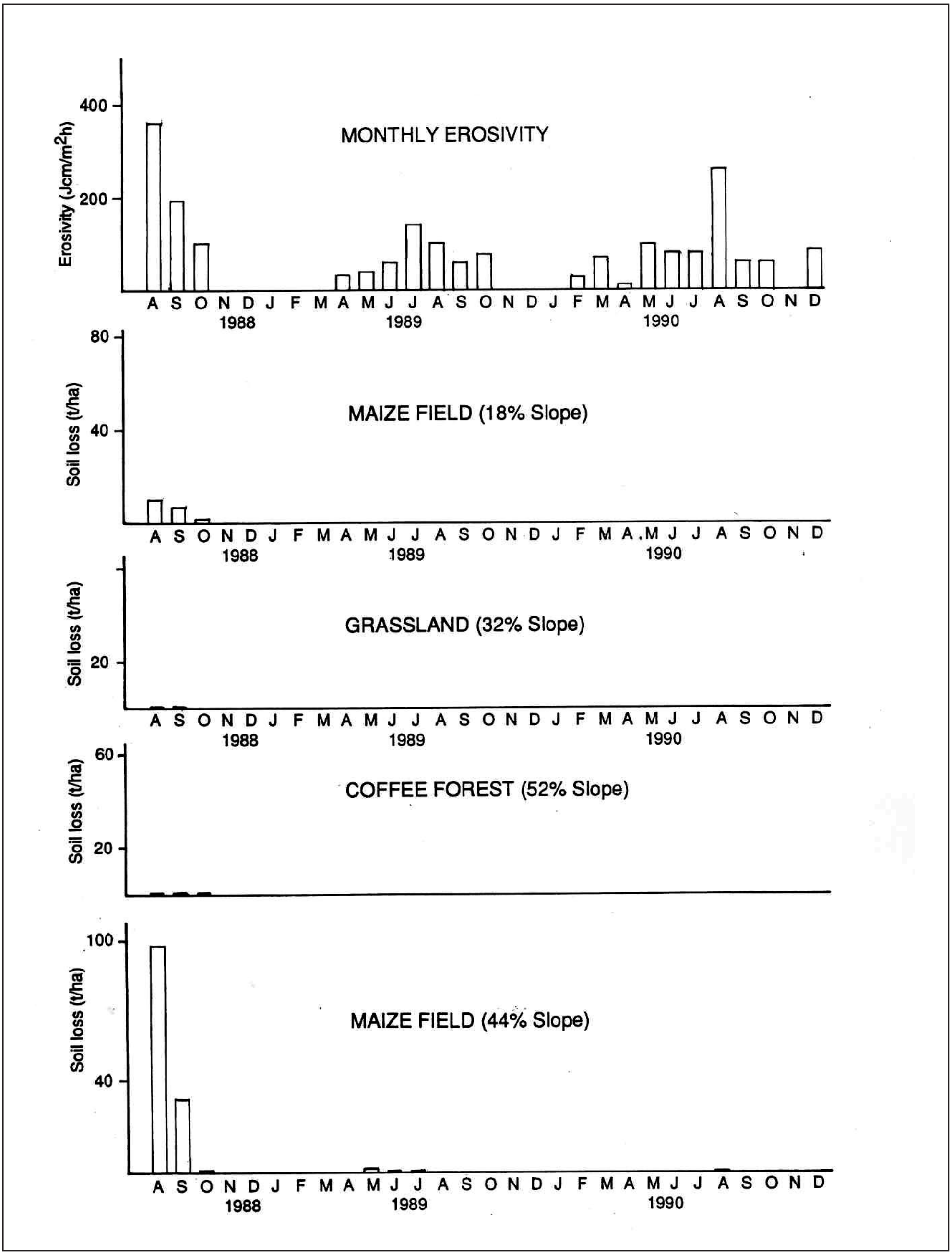

Figure A7: Monthly distribution of soil loss from test plots at Dizi Research Station (Solomon, 1994).

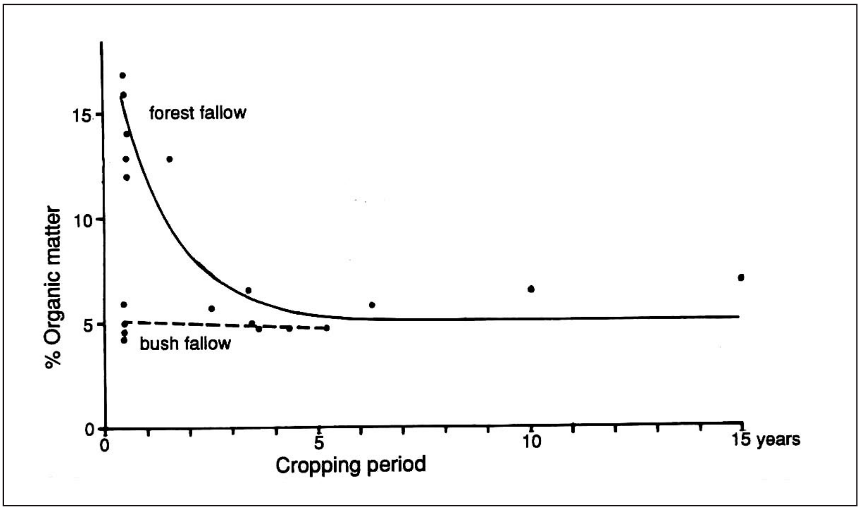

Figure A8: Decline of organic matter in forest fallow under continuous cultivation. (Hagmann, 1991)

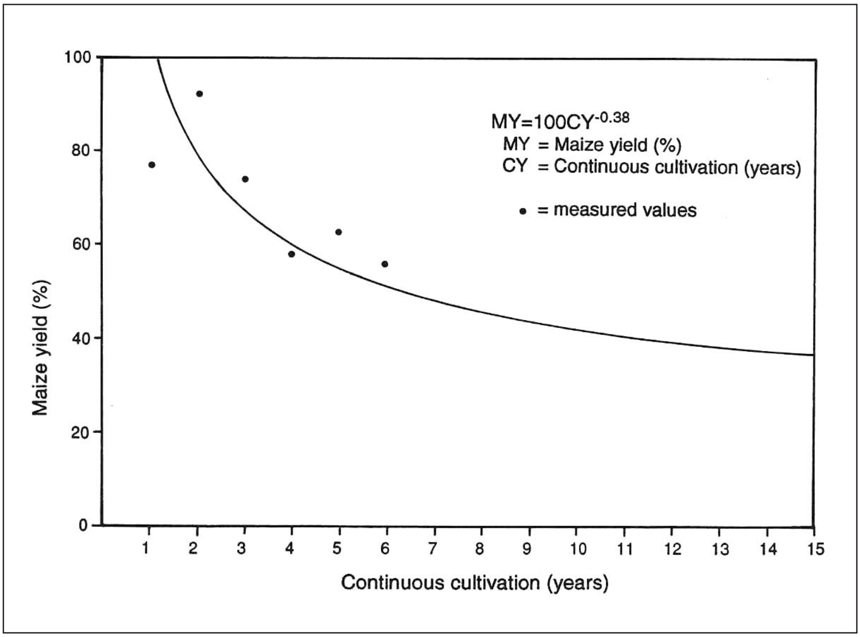

Figure A9: Maize yield in relation to continuous cultivation. (Solomon, 1994, modified after Getachew, 1991).

Table A1: Modelled changes in maize yield and productivity in realation to cultivation year and cummulative soil loss on an albic/haplic Lixisol in the basement unit on a moderatly steep slope

Cultivation year	Cumulative soil loss (mm)	Maize yield (t/ha)	Productivity (%)
0	–	–	–
1	5	6.130	100.00
2	10	4.711	76.85
3	15	4.038	65.87
4	20	3.620	59.05
5	25	3.325	54.24
6	30	3.103	50.62
7	35	2.926	47.73
8	40	2.782	45.38
9	45	2.660	43.39
10	50	2.555	41.68

Note: Based on test plot data; annual soil loss for a steep cultivated slope was estimated by taking an average from three-year measurements on test plots (Solomon, 1994).

Annex 2 Impact Monitoring and Assessment

Reference Framework: Fields of observation of sustainable land management

<table>
<tr><th rowspan="2">Level</th><th colspan="4">Dimensions of sustainability</th></tr>
<tr><th>Institutional</th><th>Socio-cultural</th><th>Economic</th><th>Ecological</th></tr>
<tr><td>Household (including farm plot level)</td><td colspan="2">▪ Education and knowledge
▪ Access to natural resources
▪ Household strategies
▪ …</td><td>▪ Household income, assets and consumption
▪ Labor and workload
▪ Land management and farming system
▪ …</td><td>▪ State of natural resources
▪ …</td></tr>
<tr><td rowspan="2">Community</td><td rowspan="2">▪ Local leadership
▪ Local institutions
▪ Producer and self-help organizations</td><td>▪ Gender issues
▪ Conflict management
▪ Innovation
▪ …</td><td>▪ Markets, prices and credit
▪ Public property
▪ …</td><td rowspan="2">▪ Land use
▪ Water resources
▪ …</td></tr>
<tr><td colspan="2">▪ Social & economic disparities
▪ …</td></tr>
<tr><td>District</td><td>▪ Education, training and extension
▪ Land and water rights, tenure
▪ …</td><td>▪ Change in social values
▪ …</td><td>▪ Employment opportunities / migration
▪ Infrastructure
▪ …</td><td>▪ Land cover
▪ Off-site effects
▪ …</td></tr>
</table>

On the following pages, the above table "Fields of observation in SLM" is used as a framework to present examples of impact hypotheses (IMA Step 3, Checklists 1a – 1c) and impact indicators (IMA Step 4, Checklists 2a – 2c, and 3a – 4c). It must be kept in mind that these checklists are by no means comprehensive; they contain only examples of hypotheses and indicators. "Positive" and "negative" formulations are context- and stakeholder-specific, which means they must always be adapted to the situation they are used in.

Checklists 1a - c: Examples of positive and negative impact hypotheses for all SLM fields of observation

Checklist 1a: Household level (including farm plot level)		
Fields of observation of SLM	**Positive impact hypotheses**	**Negative impact hypotheses**
Education and knowledge	Indigenous knowledge is recognized and strengthened	School leavers ignore local knowledge and refuse farm work
Access to natural resources	There is adequate and secure access to natural resources for all HH - women and men	Giving attention to farmers causes further
Household (HH) strategies	HH give equal importance to production and protection aspects	marginalization of landless people
HH income, assets and consumption	HH income increases; assets are increasingly re-invested in conservation-effective practices	Increasing market demand for certain crops leads to overexploitation of land resources
Labor and workload	Labor income for women and men increases	Increased HH income strengthens men's dominance over women; assets are spent for consumption of alcohol and prostitution
Land management and farming system	New practices increasingly integrate production and protection	Women's workload increases Production factors are used inefficiently
State of natural resources	Soil fertility is maintained and improved; soil degradation is minimized; agro-biodiversity is maintained; livestock rates are adapted to the carrying capacity	Inadequate soil and water conservation technologies increase soil degradation

Checklist 1b: Community level		
Fields of observation of SLM	**Positive impact hypotheses**	**Negative impact hypotheses**
Local leadership	Local leadership permits access to resources and regulations are enforced	Conflicts among community members increase due to nepotism
Local institutions	Local institutions are actively involved in resource protection	Local institutions are an obstacle to better land management
Producer and self-help organizations	Land users increasingly organize themselves	Self-help groups are inefficient because of bad management
Gender issues	Women are increasingly organized and involved in decision-making processes	Women face problems in the family due to their commitments
Conflict management	Local institutions / regulations for conflict management are functional	Conflicts are used by influential groups to maintain their position
Social and economic disparities	Social and economic disparities decrease	Profitable production encourages influential stakeholders to appropriate land
Innovation	Experimentation and innovation are recognized as integral parts of the land management system; innovators are socially accepted	Innovators are socially isolated
Markets, prices and credit	Products are sold at a profit and necessary inputs are available	Repair services for maintenance of new technologies are not available
Land use	Land use becomes more conservation-effective, i.e. degradation processes are controlled	Reduced grazing on private land triggers degradation of communal pasture land
Water resources	Sufficient water of adequate quality is always available	Water resources are not equally available to all community members

Checklist 1c: District level		
Fields of observation of SLM	**Positive impact hypotheses**	**Negative impact hypotheses**
Education, training and extension	Extensionists, teachers, land users and children are increasingly trained in sustainable land management	Indigenous knowledge is marginalized by formal education
Land and water rights, tenure	Rural population is increasingly involved in decision-making regarding land and water rights	By-laws are not enforced
Change in social values	Social control and negotiation mechanisms are maintained despite changes in social values	The younger generation loses its orientation and social roots
Employment opportunities / migration	Non-agricultural employment opportunities improve	Out-migration from the villages (loss of indigenous knowledge) increases due to more attractive income opportunities
Infrastructure	Infrastructure (roads, markets, transport, banking, etc.) improves and supports sustainable land management	Prostitution, diseases, drug trafficking and crime spread quickly
Land cover	Vegetative cover of the land increases	Farming expands to marginal lands due to higher product prices
Off-site effects	Off-site effects of resource degradation decrease	Floods affecting urban centers increase due to reduced land cover; water reservoirs are filled with sediment

Checklists 2a - c: Examples of impact indicators for all SLM fields of observation

N.B. that the formulation of the impact indicators needs to be adapted to the specific project situation!

Checklist 2a: Household level	
Fields of observation of SLM	**Impact indicators**
Education and knowledge	% of school children / No. of school drop-outs (separate for boys and girls), No. of people with school leaving certificate
Access to natural resources	No. and size of plots managed by women and men, management of communal land
Household (HH) strategies	HH structure, labor division, changes in perceptions and behavior, innovations
HH income, assets and consumption	HH income, male and female earnings, gross margins, clothing, housing, nutrition, purchasing power, spending power, months of food security, re-investment in new farm implements, seeds, etc.
Labor and workload	Labor division, labor income
Land management & farming system	Labor income, change in farming system, adapted farming practices, abandoned technologies, application rate of conservation-effective practices
State of natural resources	Soil fertility status, soil erosion, salinity, compaction, water availability and water quality, biodiversity, plant growth, plant cover, pests & diseases, No. and quality of animals

Checklist 2b: Community level	
Fields of observation of SLM	**Impact indicators**
Local leadership	Access to natural resources by women / men, actions taken when local by-laws are neglected
Local institutions	Active participation, survival rates of trees, conservation structures maintained without incentive, representation of social strata
Producer and self-help organizations	No. of farmers associations, representation of social strata
Gender issues	% of women in decision-making institutions and meetings, % of women with land titles; gender-specific access to credit, workload, income
Conflict management	Conflicts over natural resources, taboos with regulatory character, binding local agreements
Social and economic disparities	Wealth, status of minorities, clothing, housing, % of landless people
Innovation Markets, prices and credit	No. of innovative technologies, social status of innovators Distance to markets, new shops and business, No. of credits, interest rates
Land use	% of cropland, pasture, forest / bush land & other, visible signs of resource degradation, deforestation rate, cultivation of marginal land, overgrazing, abandonment of cropland
Water resources	No. of people suffering from water–borne diseases; No. of conflicts over water resources, water color, months when springs and rivers have water

Checklist 2c: District level	
Fields of observation of SLM	**Impact indicators**
Education, training and extension	District radio programs with environmental messages, farmers' and school children's environmental awareness
Land and water rights, tenure	Environmental laws, regulations, land titles, land price, local taboos with regulatory character, enforcement of regulations
Change in social values	Crime, conflicts between generations; social status of farmers
Employment opportunities / migration	Unemployment rate, vacancies, in- & out-migration, No. of female HH heads
Infrastructure	Access to markets, schools, services, credit, scholars per family, frequency, price and reliability of transport, frequency of power cuts
Land cover	% of crop, pasture, forest land

Off-site effectst	Flash floods, sedimentation of dams, water quality, destruction of roads and bridges

Checklists 3a - c: More detailed examples of SLM impact indicators

Checklist 3a: Institutional, socio-cultural, and economic aspects of SLM	
Institutional / socio-cultural aspects	
Education and knowledge	% of school children / No. of school drop-outs (separate for boys and girls), No. of people with school-leaving certificate, % of illiterate people per social strata, No. of women and men with further education & training, success rate (people trained with certificate), No. of people applying their training, No. of people instructed by those who received training (self-dissemination)
Access to resources (natural, financial, agri-services, information)	No. of households (HH) with owned, rented and leased land, land holding size per social strata (e.g. poor farms, wealthy farms), use of credits, use of production inputs
Institutions, organizational capacity, management	No. of planned development activities carried out, rate of uncompleted workdays, duration of administrative procedures, transparency of administrative procedures, application of laws and by-laws, (e.g. tax recovery, declared and sanctioned violations), public reputation of institutions, No. of binding / respected local agreements on resource use, No. of groups applying sanctions in case of violation of regulations, No. and % of functional organizations, No. of groups initiating self-help activities independent of external assistance
Gender issues	% of female HH heads, % of women in decision-making meetings, % of women with access to land, % of women in land user groups, % of women with access to extension services, % of women with access to credit, average daily workload of men and women, female and male earnings
Economic aspects	
Household income, micro-economy	Net HH income, alternative income options, % of agricultural products sold on markets, gross / net margins of individual (men's, women's) production system components, internal rate of return, purchasing and spending power, No. of (truck) loads with products arriving at local markets, No. of merchants coming to markets, quantity of produce offered on markets, fluctuation of market prices, No. of people with bank accounts, No. of houses with corrugated iron roofs, No. of people with status symbols (e.g. radio, TV, bicycle, motorcycle, etc.)

It is not possible to define "sustainable land management" globally. But it is possible to develop a vision of land management at the **local level** in terms of what is **more** or **less sustainable**, compared to previous years. This vision must be jointly developed with stakeholders, e.g. when planning a project. Since different actors have diverse perceptions of what they think is sustainable, it is not easy to select indicators of sustainability (e.g. environmental health). In contrast to this, indicators of unsustainability (poverty, overgrazing, symptoms of resource degradation, etc.) are usually easier to identify. But it must be kept in mind that the absence of indicators of unsustainability alone does not mean that land management is sustainable. It is therefore important to use both types of indicators.

- **Indicators of environmental health** describe a vision of greater sustainability of land management. They help formulate goals and indicate the directions to take.
- **Indicators of unsustainable land management** suggest that something is going wrong and serve as an **early warning system**. They show the need to confront problem issues and spend time to find the reasons as well as potential solutions.

Indicators represent a complex reality. For example, crop yield may be taken as an indicator of soil fertility. However, yield is influenced by many other factors, such as pests and diseases, rainfall variability, etc. Therefore, single indicators cannot represent a project context sufficiently. Only a **set of indicators** will provide plausible information on whether land management is moving towards or away from sustainability.

Checklist 3b: Land use and farm management aspects of SLM		
Land use types	**Environmental health indicators**	**Indicators of unsustainability**
Woodland	Afforestation, high variety of non-timber forest products	Rate of deforestation, illegal cutting
Cropland	Appropriate tillage practices, good crop stand, crop rotation, integrated pest management, integrated soil and water conservation	Monoculture, inappropriate crop rotation, soil-borne parasitic weeds and nematodes, termites and leaf-eating ants, aggressive weed (Imperata, Cyperus), decreasing length of fallow period, absence of conservation activities, abandonment of cropland, cultivation of marginal land (steep land with shallow soils)
Pasture land	Dense plant cover, high variety of species	Overgrazing, rangeland degradation, bare soil, trampled area, poor plant cover, change in species composition, increase of unpalatable species

Farm management	Good efficiency of farm resource management, high gross margins, increasing degree of organization (farmers' organizations), high return on labor, good input use efficiency, application of conservation-effective practices	Rapid changes in farming system, low gross margins, absence of farmers' organizations, low return on labor, low input use efficiency, no application of conservation-effective practices

Checklist 3c: Ecological aspects of SLM (natural resources)

Resources	Indicators	Environmental health indicators	Scenario of unsustainability
Soils	Soil fertility, nutrient status (organic matter, acidity), toxicity	Dark, deep topsoil (humus), good drain-age, high soil biological activity, earthworm casts, high earthworm density, high crop yield, high root density	Light, pale soil color, indicator plants, yellow & red color of plant leaves, small plants, poor soil drainage, no earthworms, low yield, low root density, limited rooting depth
	Creeping soil erosion: reduced topsoil depth (reduced water and nutrient re-tention capacity)	Absence of unsustainability indications	On-site: smoothened soil surface, accumulations, light soil color, exposed plant roots, increased seeding rate Off-site: brown rivers, sedimen-tation of water reservoirs
	Severe soil erosion, loss of entire topsoil		Erosion rills, gullies and large concentrated accumulations
	Wind erosion		Dust storms, mobile dunes, accumulations behind wind breaks
	Salinity & alkalinity		Salt, color of plant leaves, level of salinity in water
	Compaction		Crust formation, increased runoff, less infiltration, difficult to plow

Water	Water availability	Sufficient water	Water shortage: depletion of groundwater table, drying wells, dying trees, increase of unpalat-able species, excess water, increasing runoff, flash floods
	Water quality	Good water quality, good hygiene, clear color, no odor	Algae, bad odor, brown color, minimal variety of fish in rivers, human diseases
Checklist 3c (continued): Ecological aspects of SLM (natural resources)			
Resources	**Indicators**	**Environmental health indicators**	**Scenario of unsustainability**
Vegetation	Biodiversity	Great variety of species	Minimal variety of species, high % of unpalatable species (pasture land)
	Biomass and nutritive value	Crop residues and dung remain on the field as fertilizers	Low crop yield and biomass, high yield variability, use of crop residues and dung as fuel
	Plant growth	Uniform plant growth, tall & dense stands, green, good crop	Low plant height & cover, pests and diseases, light green or yellow / purple color of plant leaves, stunted corn, non-homogeneous ground cover
Animals	Quantity	Reasonable herd size, sufficient draft power	Overstocking: low grass cover on pasture land, encroachment on cropland
	Quality	Good livestock appearance, good productivity	Malnutrition & diseases, high mortality, low productivity, fodder shortage

Many efforts have been made in Ethiopia to mitigate land degradation, particularly soil erosion, through both local and newly introduced soil and water conservation (SWC) practices. However, the strict focus on soil erosion and conservation does not necessarily lead to satisfactory results. If SWC is effective in reducing erosion but is at the same time too costly and unacceptable to land users, sooner or later it will disappear and its positive effects will also be lost. This book therefore suggests to follow the broader approach of Sustainable Land Management (SLM), which aims at ecological soundness, economic viability and social acceptability, and thus places SWC in a more holistic framework that is closer to farmers' reality.

This, however, requires that SWC experts focus less on searching for standard solutions valid once and for all, and more on engaging in a continuous process of developing and adapting technologies with farmers. The present book was written for future SWC and land management experts in Ethiopia. It is based on results of the country's Soil Conservation Research Program (SCRP), and the experience of researchers, experts, extension workers and Ethiopian peasants. The book aims to encourage readers to take a more critical look at land problems and responses to them, to ask more critical questions, and not to take standard solutions for granted. It guides students to be open to work with – and not for – Ethiopian farmers towards more sustainable land management.

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