Chapter 3. Major causes and impacts of Land degradation

3.1. Deforestation

Deforestation is the removal of natural forest or stand of trees where the land is there after converted to a non-forest use. Forests provide essential ecosystem services such as soil erosion control, ecosystem stabilization, and moderation of climate. Forests also provide wood, food, medicines, and many other wood-based products. Excessive logging and clear-cutting, expansion of agriculture to marginal lands, frequent fires, construction of roads and highways, and urbanization are the main causes of deforestation. For example about 15 M ha yr^{-1} of forest are cleared annually worldwide and the rate of soil erosion is projected to accelerate with increase in deforestation. Forests are disappearing more rapidly in developing than in developed countries. About half of the deforested areas are left bare or abandoned. Runoff and soil erosion rates are high from deforested areas. In sloping lands, clearing of forest for agriculture can increase soil erosion by 5- to 20-fold. Deforestation is taking place at a faster rate due to increasing demands of timber, agriculture, industries, fuel and forest products which results into degradation of land resources.

Examples of deforestation include:

- ✓ conversion of forestland to farms, ranches, or urban use.
- ✓ The removal of trees without sufficient reforestation has resulted in damage to habitat, biodiversity loss and aridity.

The removal of vegetation has resulted in:

- ✓ The reduction of the natural vegetative cover which renders the topsoil more susceptible to erosion
- ✓ Adverse impacts on bio sequestration of atmospheric carbon dioxide.
- ✓ Increased surface runoff and stream discharge
- ✓ Reduction of water infiltration and groundwater recharge
- ✓ Development of erosional gullies and sand dunes
- ✓ Change in the surface microclimate that enhances aridity
- ✓ Drying up of wells and springs, and
- ✓ Reduction of seed germination of native plant, etc.

3.2. Overgrazing

Refers to excessive eating of grasses and other green plants by cattle, it results into reduced growth of vegetation, reduced diversity of plant species, excessive growth of unwanted plant species. **Overgrazing** is herds of cattle and sheep are often concentrated on the same piece of land for too long in many livestock farms. This confinement results in **overgrazing, repeated trampling or crushing, and soil displacement during traffic**. Removing or thinning of grass reduces the protective cover and increases soil erosion particularly on steep slopes or hillsides. Overgrazing reduces soil organic matter content, degrades soil structure, and accelerates water and wind erosion.

Trampling by cattle causes soil compaction, reduces root proliferation and growth, and decreases water infiltration rate and drainage. Increase in stocking rate results in a corresponding increase in runoff and soil erosion in heavily grazed areas. In wet and clayey soils, compaction and surface runoff from overgrazed lands can increase soil erosion. Increased erosion from pasturelands can also cause siltation and sediment-related pollution of downstream water bodies.

In dry regions, animal traffic disintegrates aggregates in surface soils and increases soil's susceptibility to wind erosion. Continuous grazing increases the sand content of the surface soil as the detached fine particles are preferentially removed by flowing water and wind.

3.3. Land use mismanagement

Expansion of agriculture to sloping, shallow, and marginal lands is a common cause of soil erosion. Intensive agriculture and plowing, wheel traffic, shifting cultivation((forest to cultivated land), indiscriminate chemical input, irrigation with low quality water, and absence of vegetative cover degrade soils. Removal of crop residues for fodder and bio-fuel and industrial uses reduces the amount of protective cover left on the soil surface below the level adequate to protect the soil against erosion. Intensive cultivation accelerates water runoff and increase soil erosion, which transport nutrients and pesticides off-site, declining soil and water quality.

Shifting cultivation, a system in which depleted soils are abandoned to recover while new lands are cleared for cultivation, often worsens soil erosion as the duration of the fallow phase. It often involves slashing and burning of forest or pasturelands to create new croplands, as a common practice. Degraded soils require a longer period (5 to 40 yr) of time to fully recover. In some regions, because of the high population pressure and scarce arable land area, farmers are forced to use hilly, marginal or degraded lands for crop production.

The most important causative factor of soil degradation.

- In appropriate or heavy machinery is applied on farmers grassland
- Steep slopes are cultivated in areas that are marginal in terms of rainfall, even for the production of crops.
- Land left uncovered after cropping is prone to wind and water erosion.
- Unsustainable land use practices such as excessive irrigation, inappropriate use of fertilizers and pesticides and overgrazing by livestock.

3.4. Population pressure

Rapid population growth puts tension on natural resources which results in degradation of our environment. Population pressure puts considerable pressure on its natural resources and reduces the gains of development. Hence, the greatest challenge before us is to limit the population growth.

- More population means more demand for food, clothes and shelter,
- You need more space to grow food and provide homes to millions of people,
- This results in deforestation which is another factor of environmental degradation.

3.5. Urbanization

Urbanization and industrialization has given birth to a great number of environmental problem that need urgent attention. It is a population shift from rural to urban areas, "the gradual increase in the proportion of people living in urban areas", and the ways in which each society adapts to the change? Increasing growth of population and demand for more residential areas and commercial sectors is also one of the reasons for land degradation. Hence, coping with rapid urbanization is a major challenge.

3.6 . Land tenure

Land tenure is the terms and conditions on which land and other natural resources (such as trees and water) are held and used. Resources are usually categorized into management regimes so as to understand the manner in which they are owned, accessed, controlled, and used. Poorly defined tenure security/access rights may lead to land degradation, as individual investments in maintenance and enhancement can be captured by others and land users do not feel owner of the maintenance investments.

There are four resource management regimes:

(i) **Private property regime**: Rights of ownership are vested on an individual owner, or group defining his/her rights privileges and limitations for use of a resource which should ideally be immune from government interference. A private right assigns specific access and use to the holder of the rights.

(ii) State property regime: Rights of ownership and management of natural resources are vested in the state (government). Individuals or groups may make use of the resources but must seek permission from the state. Examples include national parks and forests that are managed by the state.

(iii) Open access regimes: signifies the absence of property rights. Nobody owns the resources here and access to them is on a 'first come first served basis'. Individuals or groups of people are allowed to make use of the scarce resources without regard for the interests of others who may also seek to make use of the same resources. In an open access regime, a resource belongs to the first person to exercise control over it the rule of first capture. Open access results from the absence or the breakdown of a management.

(iv) Common Property Regimes (CPR): Rights of ownership and access are vested on a single entity and limited to an identifiable community which has set rules on the way those resources are to be managed. In most common property regimes the rules on resource extraction always appear to some authority higher than the individual users or any sub-set of users. Such authority could emanate from the area chief, a democratic governing body, and a government agency among others. Non-members are excluded from the use of resources managed by a different group. For example- land among the traditional pastoral communities is controlled on customary tenure basis usually by a group. The leaders of the group or a council of elders allocate 'user rights' on portion of the land to various individuals or families. Tenure systems are particular important factors when conservation practices have a longlag between investment and return, such as terracing and tree planting.

3.7. Climate change

Climate change: Climate exerts a strong influence over dry land vegetation type, biomass and diversity. Precipitation and temperature determine the potential distribution of terrestrial vegetation and constitute the principal factors in the genesis and evolution of soil. Precipitation also influences vegetation production, which in turn controls the spatial and temporal occurrence of grazing and favors nomadic lifestyle. In generally high temperatures and low precipitation in the dry lands lead to poor organic matter production and rapid oxidation. Low organic matter leads to poor aggregation and low aggregate stability leading to a high potential for wind and water erosion.

3.8. Pollution

Pollution: Degradation of land is almost a natural "continuation" of air and water pollution. Deposition of air pollutants onto the soil and seeping of water pollutants through to adjacent land areas lead to land contamination and its quality deterioration. **Land pollution** is the deterioration (destruction) of the earth‘s land surfaces, often directly or indirectly as a result of man‘s activities and their misuse of land resources. It occurs when waste is not disposed of properly, or can occur when humans throw chemicals onto the soil in the form of **pesticides, insecticides and fertilizers** during agricultural practices. Exploitation of minerals (mining activities) has also contributed to the destruction of the earth‘s surface.

3.9. Loss of biodiversity

Biodiversity is important for maintaining balance of the ecosystem in the form of combating pollution, restoring nutrients, protecting water sources and stabilizing climate. Biodiversity is diminished or destroyed in a number of ways either by natural changes or by human disruption. The loss of even a single species is considered as a tragedy as each form of life is a natural storehouse of irreplaceable substances the genetic materials. As species become extinct, the fine balance of nature is disturbed to great extent. The loss of even a single species can alter a food chain/food web, i.e. ecosystem disruption, and upset the delicate balance between one species that preys upon another. Deforestation, global warming, overpopulation and pollution are few of the major causes for loss of biodiversity.

3.10. Desertification

Desertification

Meaning of Desertification: Desertification can be defined as a process of degradations of the environment that usually is a product of climate and human activity and involves the spread of extension of desert-like conditions in a hither to fertile area.

In this way Desertification process is leading to desert formation, it may be either due to a natural phenomenon linked to climatic change or due to abusive land use. However, the improper land use practices besides soil erosion greatly lead to climatic change. Removal of vegetal cover brings about marked changes in the local climate of the area. In this way deforestation and overgrazing etc. bring about changes in rainfall, temperature, wind velocity etc. These lead to desertification of the area. Desertification often starts as patchy destruction of productive land.

Causes of Desertification

Main causes of desertification are as under:

(1) The population explosion in man and livestock. It has led to enhanced requirement of timber and fuel wood. Besides, increasing number of livestock causes degradation of forests and the consequent devastation.

(2) Revenue Generation

Maximum has been extracted from the trees by Govt. and private owners. In the face of agriculturalisation, urbanization and industrialization, preservation of forests could be given a very low priority.

(3) Road Construction

The construction of hill roads is a major cause of deforestation.

Road construction caused desertification in the following way:

- It affected the stability of hill slopes,
- It damaged the protective vegetation over both above and below roads,

(4) Industries and Mining

These have a serious impact in forest areas. Large areas have been clear-felled and laid barren consequent to open cast mining of iron ore, mica, coal, manganese, limestone etc.

Environmental impact of mining includes loss of production for the following reasons:

- The forests, agriculture turned into pastures,

- The loss of top soil,
- The surface water pollution,
- The lowering of ground water table,
- Ore transport hazards such as damage to vegetation, soil drainage, water quality and property, sediment production and discharge, fire hazards and air pollution.

(6) Development Projects

There are hasty approaches to formulation of developmental projects particularly hydroelectric besides those on tourism, road building and mining.

(7) Commercial Demand

In comparison of commercial demand supply fell short and led to decimation of forests, particularly the wood. Consequently there has been unlimited exploitation of timber for commercial use, etc.

(8) Over grazing

When the vegetation cover is destroyed, it leads to soil erosion and irreversible destruction of ecosystem. There occur different types of desertification in various continents and ecosystems.

Two main objectives for mapping desertification have been identified as under:

(1) To assist decision-makers to understand the various dimensions of desertification,

(2) To assist scientists to make the best choice in selecting strategies for desertification control, to reduce the impact of land degradation.

Chapter 4. Land degradation assessment

Land degradation is increasing in severity and extent in many parts of the world, with more than 20% of all cultivated areas, 30% of forests and 10% of grasslands undergoing degradation (Bai et al., 2008). Millions of hectares of land per year are being degraded in all climatic regions. It is estimated that 2.6 billion people are affected by land degradation and desertification in more than a hundred countries, influencing over 33% of the earth´s land surface (Adams and Eswaran, 2000). The decline in land quality caused by human activities has been a major global issue since the 20th century and will remain high on the international agenda in the 21th century (Eswaran et al.,2001).The immediate causes of land degradation are inappropriate land use that leads to degradation of soil, water and vegetative cover and loss of both soil and vegetative biological diversity, affecting ecosystem structure and functions (Snel and Bot, 2003). Degraded lands are more susceptible to the adverse effects of climatic change such as increased temperature and more severe droughts.

Land degradation encompasses whole environment but includes individual factors concerning soils, water resources (surface, ground), forests (woodlands), grasslands (rangelands), croplands (rain fed, irrigated) and biodiversity (animals, vegetative cover, soil) (FAO, 2005).

Estimate for each physically-homogeneous mapping unit

- Type of degradation: (water/ wind erosion; chemical/ physical deterioration)
- Degree of degradation: (light, moderate, strong, extreme)
- Causes: (deforestation, overgrazing, agricultural activities, overexploitation of vegetation, industrial activities)

Land degradation Assessment

Land Degradation **A**ssessment in **D**ryland **A**reas (**LADA**)

LADA follows a **participatory, decentralized, country-driven and integrated approach** and makes ample use of participatory rural appraisals, expert assessment, field measurements, remote sensing, GIS, modeling and other modern means of generation of data, networking and communication technologies for sharing information at national and international levels (Koohafkan et al., 2003; LADA project document, 2005).

- LADA considers both biophysical factors and socio-economic
- Intended to make an innovative generic contribution to methodologies and monitoring systems for land degradation
- The six main partner countries involved in the LADA project are
  - ✓ Argentina – for the Latin America region,
  - ✓ China – for the East Asia region,
  - ✓ Cuba – for the Caribbean region,
  - ✓ Senegal – for the West Africa,
  - ✓ South Africa – for the southern, central and eastern Africa region, and
  - ✓ Tunisia – for the Near East, North Africa and Mediterranean region (LADA project document, 2005).

They proposed that the causes, status and impact of land degradation and possible responses can be determined and assessed at the same time. The proposed LADA methodology was based on the DPSIR framework where D indicates the driving forces, P the pressures, S the condition of land and its resilience, I the impacts of the increased or reduced pressures, and R the responses by the land users to release or reduce the pressures on the land.

- Indicators on the biophysical condition of land, on how land is being managed, and the policy and social environment for instituting improvement in land management are discussed.
- Based on a review of existing land degradation indicators, data sources and methods, and expert consultation.
- Based on the list of potential indicators for uses at global, national, and regional, watershed or village and farm levels

Land Degradation Assessment Methods

The most common methods used to assess land degradation are:

- ➢ Expert opinions
- ➢ Land users‘ opinions,
- ➢ Field monitoring,
- ➢ Observations and measurement,
- ➢ Modelling,
- ➢ Estimates of productivity changes and remote sensing.

(a): Global level

Units/Systems assessed	Methods used	What was assessed	Units / values
Full Cover Analysis Partial cover (soils/ rangelands/ agricultural lands/ drylands, etc.)	**Experts opinion** (e.g. indicators, questionnaires, etc.) **Remote sensing and GIS** (e.g. mapping)	Land/soil degradation: (severity, degree, extent) Soil (erosion, fertility, productivity, etc.) Vegetation change Biodiversity loss	%, Classes (1,2,3,4,5 -light – very severe / excellent – very poor, etc.), t/ha/yr

b.. Regional level indicators of land degradation

Units/Systems	***Assessed methods used***	***What will be assessed***	***Units / values***
Dry lands, rangelands, grasslands, forests, deserts, etc., Soils, Rivers systems, etc	***Expert opinion*** (E.g. Indicators, questionnaires, interviews, focus groups, etc…) ***Remote Sensing and GIS*** (e.g. NDVI, MODIS, etc.) ***Modeling***(e.g CORINE, PESERA erosion models, etc.) (mainly for croplands) ***Field Monitoring and Measurements*** (measurements to verify models) -pilot areas ***Grid System Monitoring***	Land/soil degradation: ➢ severity, degree, extent, impact, causes, & risks ➢ Soils (erosion, fertility, productivity, etc. ➢ *Vegetation change, Land cover, Land uses, Slopes* ➢ *Climate (rainfall, temperature)* ➢ *Biodiversity loss* ➢ *Landscapes/ Ecosystem function* ➢ *Biodiversity loss* ➢ *Landscapes/ Ecosystem function*	- %, - Classes (1, 2,3,4,5 light – very severe / Excellent – very poor, etc.), - Tone /hectare/year

c. *National level* **indicators of land degradation**

Units/Systems	*Assessed methods used*	*What will be assessed*	*Units / values*
Lands (cropland lands, grasslands, forests, conserved area, deserts etc.), Soils, Rivers, Rangelands, etc	***Expert opinion*** (e.g. indicators, questionnaires,) ***Land users opinion*** (e.g. indicators etc.) ***Remote Sensing and GIS*** (e.g. NDVI, MSDI etc.) **Modeling** (e.gCORINE, PESERA models, etc.) ***Field Monitoring and Measurements***(verify models) plot area	Land/soil degradation: ➢ (severity, degree, extent) ➢ Soil (erosion, fertility, productivity, etc. ➢ Vegetation change ➢ Biodiversity loss ➢ Land cover ➢ Land uses ➢ Rangeland ➢ health/conditions, ➢ Climate (rainfall, ➢ temperature), etc	➢ %, ➢ Classes(1, 2,3,4,5 light – very severe / Excellent – very poor, etc.), ➢ Tone /hectare/year

d. ***Local and Field/Farm levels*** indicators of land degradation

Units/Systems	*Assessed methods used*	*What will be assessed*	*Units / values*
Lands (cropland lands, grasslands, forests, conserved area, deserts etc.), Soils, Rivers, Rangelands, etc.	***Expert opinion*** (e.g. indicators, questionnaires,) ***Land users opinion*** (e.g. indicators etc.) ***Remote Sensing and GIS*** (e.g. NDVI, MSDI etc.) **Modeling** (e.g USLE/ RUSLE, CORINE, PESERA models, etc.) ***Field Monitoring and Measurements***(verify models)-farm plots estimates of productivity changes	Land/soil degradation: ➢ Severity, degree, extent, impact, causes, & risks;, ➢ Soil erosion(Sediment yields ➢ Rangelands Health/ Condition ➢ Soil condition (quality, salinity, stability, fertility, etc.), Crop yield & suitability, Soil condition, ➢ Landscape/ ecosystem function,Land cover,Biodiversity loss,Land uses, ➢ Climate (rainfall, temperature), etc.	➢ %, ➢ Classes (1, 2,3,4,5 light – very severe / Excellent – very poor, etc.), ➢ Tone /hectare/year

The methods have been applied to different approaches which use either qualitative or quantitative measures or both. The table (a – d) summarizes the systems assessed; assessment methods used; factors/processes/ and parameters of the land that is being assessed; and the units or values in which measurements were given for the different assessments of land degradation at different levels. Details are identified at the global, national, regional, and local and field/farm level. Above is a summary of the different assessment methods used in assessing land degradation processes in different systems at different levels.

Assessment with land degradation indicators

Desertification and land degradation are complex processes with causes that range from climate change to change in land use or change in environmental protection legislation. The way in which an area responds to these pressures is determined by how resilient the landscape (soil, water, vegetation) and local economy are. Indicators are often used as a tool to understand this complexity and to help answer questions such as:

- ✓ How vulnerable is this area to desertification?
- ✓ How rapidly is the land degradation progressing?
- ✓ How effective are the actions that we are taking to mitigate it?

Land degradation indicators are

- ✓ An indicator is a parameter (or value derived from parameters) which provides information about a phenomenon.
- ✓ Indicators are quantified information which helps to explain how things are changing over time and space for decision making.
- ✓ An environmental indicator is a parameter which provides information about the situation or trends in the state of environment, in the human activities that affect or are affected by the environment or about relationships among such variables.
- ✓ Land degradation indicators are a sub-set of environmental indicators focusing on a particular trend in state of the environment and associated human activities.

Uses of land degradation indicators

To use indicators as the appropriate tool to provide operational support to a wide range of activities such as: assessing mapping the extent of desertification as well as determining the causes; quantifying the impacts; justifying expenditure for mitigation measures and monitoring the efficiency of the measures undertaken. Indicators that might be used for assessing land degradation in dry lands. Indicators of land degradation are rills, water flows pattern, pedestals, bare ground, gullies, wind-scoured and depositional areas, litter movement, soil surface resistance to erosion, soil surface loss or degradation, plant community composition and distribution relative to infiltration and runoff, compaction layer, functional/structural groups, plant mortality/decadence, litter amount, annual production, invasive plants, and reproductive capability of perennial plants.

Available models for different levels

Assessment of soil erosion and land degradation both by water and wind has been carried out using models designed for the purpose. The mathematical models are continually being improved and scientists from many countries have adopted them to meet the requirements of their local conditions (Arnalds et al., 2001). Many more models have now been developed and used by different countries in different regions. Below is a summary of several models for measuring soil erosion and land cover used in different environments

The Universal Soil Loss Equation (USLE) and its revised version RUSLE are two of the empirical models that have been most widely used and generally accepted by the natural resources community because they are relatively easy to use and its spatial distribution feasible with reasonable costs and better accuracy in larger areas (Saavedra, 2005).

The RUSLE model can predict erosion potential on a cell-by-cell basis (Shinde *et al*., 2010), which is effective when attempting to identify the spatial pattern of the soil loss present within a large region and it needs less input required data than other model. Now a day's, so many researches are using **remote sensing and GIS software with RUSLE model** to estimate the rate of soil erosion and mapping erosion risk areas. Other soil erosion models range in various degrees of complexity, they needs large input data, takes time and money, models like

EUROSEM (European Soil Erosion Model),

ANSWERS (Areal Nonpoint Source Watershed Environment Response Simulation),

CREAMS (Chemicals, Runoff and Erosion from Agricultural Management Systems), and **MODANSWERS** (modified ANSWERS), are basically conceptual and event based models. **INRA model** Institute National Recherche Agronomique, which takes into account crust formation, land use and soil erodibility.

SLEMSA Model - the Soil Loss Estimation Equation, for Southern Africa

MMF Model - the Morgan-Morgan Finney model, to provide useful information on the source areas of sediment, sediment delivery to streams

WEPP Model - the Water Erosion Prediction Project

SWAT- Soil and Water Assessment Tool

The RUSLE model

The soil erosion assessment was estimated under ArcGIS environment using **Revised Universal Soil Loss Equation (RUSLE)** model for the study area. The five erosion factors cover management (C), rainfall erosivity (R), soil erodibility (K), slope steepness- length (LS) and conservation practice (P) were estimated and were used for the estimation of average annual soil loss.

A = R. K. L.S. C. P

where: -

A = spatial average soil loss rate (t/ha /year),

R = rainfall-runoff erosivity factor [MJ mm/ (ha h year-1)],

K = soil erodibility factor [t ha h/ (ha MJ mm)],

L = slope length factor,

S = slope steepness factor,

C = cover management factor, and

P = conservation support practice factor

The study produced maps that show the rate of soil erosion by water in the watershed.

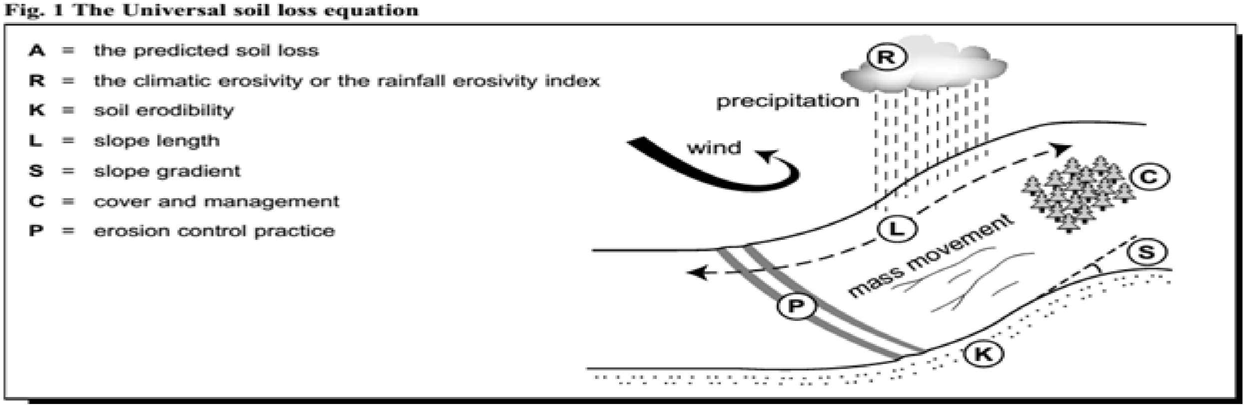
- ✓ Calculates the actual sediment loss by soil erosion
- ✓ To evaluate the different scenarios of land uses
- ✓ To assess landscape soil erosion susceptibility with scenario analysis
- ✓ To develop adaptation strategies for future climate change scenarios such as modification in land management techniques.
- ✓ To assess the risk of land degradation on large scale agricultural lands

as well as the techniques used for continuous monitoring.

- ✓ Capable of predicting soil loss from fields or hill slopes

Identification of areas with high degradation risks will allow for better soil conservation plans to reduce the sediment load to the rivers and lakes in the region of interest

Fig. 1 The Universal soil loss equation



1. Rainfall erosivity factors

Rainfall erosivity defined as the aggressiveness of the rain to cause erosion. The numerical value used for R in RUSLE and USLE must quantify the effect of raindrop impact and must also reflect the amount and rate of runoff likely to be associated with the rain. The soil loss is closely related to rainfall partly through the detachment power of raindrop striking the soil surface and partly through the contribution of rain to runoff. This applies particularly to erosion by overland flow and rills for which intensity generally considered the most important rainfall characteristics. It is a statistic calculated from the annual summation of rainfall energy in every storm (correlates with raindrop size) times its maximum 30 - minute intensity. As expected, it varies geographically. The greater the intensity and duration of the rain storm, the higher the erosion potential.

Table 1. R: Rain fall ersosivity

Annual rainfall (mm)	100	200	400	890	1200	1600	2000	2400
Annual factor (R)	48	104	217	441	666	890	1115	1340

2. Soil erodibility factor (K)

The susceptibility of soil to erosion agents is known as **soil erodibility**. Soil erodibility is the manifestation of the inherent resistance of soil particles for the detaching and transporting power of rain fall. This factor quantifies the cohesive character of a soil type and its resistance to dislodging and transport due to raindrop impact and overland flow. Those soil erodibility factors refer the effect of soil on erosion through the resistance of soil to both detachment and transport. Due to a function of a range of soil properties such as soil texture, structure, soil moisture, roughness, organic matter content and chemical and biological characteristics, soils are different in their resistance to erosion. In general, soils having faster infiltration rates, higher levels of organic matter and improved soil structure have a greater resistance to erosion.

K is the average soil loss in tonnes/hectare (tons/acre) for a particular soil in cultivated, continuous fallow with an arbitrarily selected slope length of 22.13 m (72.6 ft) and slope steepness of 9%. K is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. Texture is the principal factor affecting K, but structure, organic matter and permeability also contribute.

Table 2. K: soil erodibiltiy

Soil colour	Black	Brown	Red	Yellow
Factor (K)	0.15	0.20	0.25	0.30

3. Topographic factors

The effect of topography on soil erosion is accounted for by the LS factor, which combines the effects of a slope length factor (L) and a slope steepness factor (S). Wishmeier and Smith (1978) defined slope length as the distance from the point of origin of overland flow to the point where the slope decreases enough that deposition begins or the point where runoff becomes concentrated in a defined channel. Slope steepness reflects the influence of slope gradient on soil erosion. It is known that the amount of runoff increases due to the continuous accumulation down the slope as the slope length (L factor) increases; the velocity of runoff increases as the slope steepness (S factor) increases. Steeper slopes produce higher overland flow velocities. Longer slopes accumulate runoff from larger areas and also result in higher flow velocities. Thus, both result in increased erosion potential, but in a non - linear manner. For convenience L and S are frequently lumped into a single term. LS is the slope length-gradient factor. The LS factor represents a ratio of soil loss under given conditions to that at a site with the "standard" slope steepness of 9% and slope length of 22.13 m (72.6 ft). The steeper and longer the slope, the higher the risk for erosion.

3. L: slope length

Length (m)	5	10	20	40	80	160	240	320
Factor (L)	0.5	0.7	1.0	1.4	1.9	2.7	3.2	3.8

4. S: Slope gradient

Slope (%)	5	10	15	20	30	40	50	60
Factor (S)	0.4	1.0	1.6	2.2	3.0	3.8	4.3	4.8

4. Cover factor

The C-factor is defined as the ratio of soil loss from land cropped under specified conditions to the corresponding clean-tilled continuous fallow. To account for the effect of vegetation in erosion assessments, a cover and management factor (C-factor) has often been used. Land use classification is often used to map vegetation types that differ in their effectiveness to protect the soil. Vegetation reduces soil erosion by: protecting the soil against the action of falling raindrops, increasing the degree of infiltration of water into the soil, reducing the speed of the surface runoff, binding the soil mechanically, maintaining the roughness of the soil surface, and improving the physical; chemical and biological properties of the soil. C is the crop/vegetation and management factor. It is used to determine the relative effectiveness of soil and crop management systems in terms of preventing soil loss. The C Factor can be determined by selecting the crop type and tillage method (see below **Table)** that corresponds to the field and then multiplying these factors together.

5. Conservation practice factor

The management practice factor P indicates the effect of conservation practices on soil erosion, wherein the land which has adequate conservation interventions. Specific cultivation practices affect erosion by modifying the flow pattern and direction of runoff and by reducing the amount of runoff. Especially in agricultural areas, conservation practices such as contouring, strip cropping, or terracing, reduce soil losses. For instance, in areas where there is terracing, runoff speed could be reduced with increased infiltration, ultimately resulting in lower soil loss and sediment delivery. The effectiveness of such practices is often analyzed with a support practice factor (P-factor).

Table : C and P factors and their related factor values

C – factor (land cover)	P – factor (management /conservation factor)
➢ Dense forest………0.001	➢ Plough up and down…………………… 1.0
➢ Dense grass…………. 0.01	➢ Contour plough………………………….. 0.9
➢ Degraded grass …….0.05	➢ Applying mulch …………………………0.6
➢ Other forest …………0.01	➢ Strip cropping ……………………………0.8
➢ Fallow (surface crust) ..0.05	➢ Inter cropping ……………………………0.8
➢ Fallow ploughed ……..0.06	➢ Grass strip ……………………………….0.8
➢ Sorghum, maize ……0.10	➢ Grass strip ……………………………….0.8
➢ Cereal, pulses …….0.19	➢ Bund, good shape ………………………0.7
➢ Teff …………………0.25	➢ Bund, degraded………………………….. 0.9
➢ No till ………………0.1	➢
➢ Maize in a continuous fallow…..0.36	➢ Bench terrace- narrow based degraded…… 0.9
➢ Cross slope farming ….0.75	➢ 0.08 Contour stone bund spacing ((20-50 m)… 0.7
➢ Continuous fallow ……1.0	➢ Contour stone bund spacing…..
➢ Stone cover…………. 40%	➢
➢ Stone cover(80%)……. 0.04	➢
➢ Rock outcrop ……….0.00	➢

Example 1: given the following conditions in a sample agricultural field, calculate soil erosion using USLE.

Rainfall and Runoff Factor (R), the R factor=100

Soil Erodibility Factor (K)

The sample field consists of fine sandy loam soil with an average organic matter content of K factor= 0.40

Slope Length-Gradient Factor (LS)

The sample field is 244 m (800 ft) long with a 6% slope. The LS factor = 1.91

Crop/Vegetation and Management Factor (C)

C Factor = 0.4 x 0.9 = 0.36

Support Practice Factor (P)

Cross-slope farming is used (P Factor was obtained from= 0.75). Calculate A

Therefore,

A = R x K x LS x C x P = 100 x 0.40 x 1.91 x 0.36 x 0.75

= 20.63 tonnes/hectare/year (9.28 tons/acre/year)

The soil loss rate of 20.63 tonnes/hectare/year is in the moderate range and considerably higher than the "tolerable loss level" of 6.7 tonnes/hectare/year. Therefore, you advise the land user to reduce the soil losses for this sample field below 6.7 tonnes/hectare/year by making the following changes to the above example and table 1.

In order to reduce the soil loss, change the tillage method from "spring plow (0.9)" to "no-till (0.25)". Therefore, C Factor (revised) = 0.4 x 0.25 = 0.10

The adjusted annual soil loss value is

A = R x K x LS x C x P = 100 x 0.40 x 1.91 x 0.10 x 0.75 = 5.73 tonnes/hectare/year

Thus by changing the tillage practice, the average annual predicted soil loss for this field is below the "tolerable soil loss" of 6.7 tonnes/hectare/year.

Thinking Questions:

1. Explain how each of the six factors in the Universal Soil Loss Equation (USLE) influence the amount of soil lost by water erosion.
2. Which of the factors of the USLE can be controlled by the land manager?
3. Are there differences in the amount of soil lost if a land user introduces some topographical, land cover and land conservation practices? Why or why not?
4. How does increase % residue cover can reduce the rate of soil loss change? Explain.
5. Assume a land user who used to plough up and down for the last 5 years has managed and changed in to broad base bench terrace, good shape. Discuss how much the new land management has helped reduce the annual soil loss.

CORINE model

CORINE methodology is a standard method used by the countries of the European Community to determine the erosion risk and qualities of the land being studied (Doğan et al., undated). Countries of the European Community sharing the Mediterranean region have completed their erosion maps and classification of their lands using CORINE methodology (Doğan et al., undated).

- ✓ Determines the actual erosion risks for vegetative cover, land slope, meteorological condition and soil properties.
- ✓ The model consists of 6 steps, each of which uses different overlaying combinations of soil texture, depth, stoniness; climatic data, land use and land cover information.

- ✓ Consequences of land cover changes on soil erosion distribution
- ✓ Provided complete and appropriate assessment of land degradation and can be used to improved degradation assessment in other semi-arid areas

Chapter 5. Rehabilitation and/or restoration of degraded land

Rehabilitation: Repair damaged or blocked ecosystem functions, with the primary goal of raising ecosystem productivity for the benefit of local people. It attempts to achieve such changes as rapidly as possible. Rehabilitation and restorations, they aim at recreating autonomous or self-sustaining ecosystems, which are characterized by biotic change or succession in plant and animal communities, and the ability to repair themselves following natural or moderate human perturbations. Thus, restoration and rehabilitation projects must also share as explicit or implicit working goals the return to former paths of energy flow and nutrient cycling, and the reparation of conditions necessary for effective water infiltration and cycling throughout the ecosystem.

Restoration invariably seeks a direct and full return to the indigenous, historic ecosystem, restoration sense late and, particularly, rehabilitation may settle on one of many possible alternative steady states, or a synthetic simplified ecosystem as an intermediate step in their long-term goals. The alternative steady states might or might not have occurred in the process of degradation of the original, pre disturbance ecosystem.

5.1. Vegetation

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, and 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 aim at an optimal plant cover over a longer period of time.

Vegetation Rehabilitation:

- Recreate healthier ecological conditions
- Re-establish more open landscape
- Recreate historic balance between grassland and woodland
- Along streams, gullies and ravines
- Along boundaries as screening plantings
- In areas of high soil erosion hazard
- In places where woodlands occurred historically

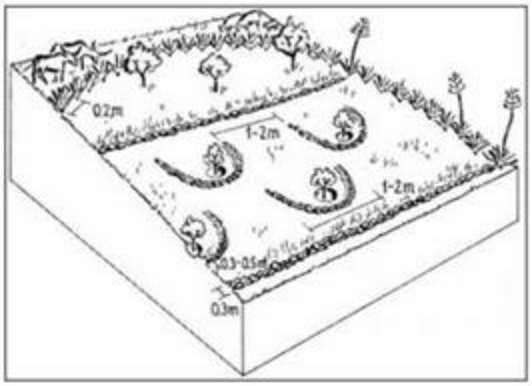
5.1.1. Area closure

Commonly alternative names for area closure practice include exclosure, closed area, and enclosure. Enclosing and protecting an area of degraded land from human use and animal interference, to permit natural rehabilitation, enhanced by additional vegetative and structural conservation measures. Area closure involves the protection and resting of severely degraded land to restore its productive capacity. Their main objective of area closure is to allow native vegetation to regenerate as a means of providing fodder and woody biomass, to reduce soil erosion and to increase rain water infiltration. There are two major types of area enclosures practiced in Ethiopia:

1. ***Passive or natural regeneration:*** the most common type involves closing of an area from livestock and people so that natural regeneration of the vegetation can take place;

2. ***Assisted or accelerated regeneration:*** comprises closing off degraded land while simultaneously implementing additional measures such as planting of seedlings, mulching and establishing water harvesting structures to enhance and speed up the regeneration process.

The selection of measures chosen for rehabilitation depends mainly on the land use type, climate, topography and soil type. Degraded croplands with individual land use rights are normally treated with additional structural measures to retain soil moisture and trap sediment, and with agronomic measures to restore soil fertility. Open access grazing lands areclosed for natural regeneration while partly treated with additional measures, and open access woodlands are simply closed. Structural measures such as micro-basins, trenches, and bunds that enhance water infiltration and soil moisture may be constructed to increase survival rate of vegetative material planted. The maintenance of area enclosures involves activities such as replanting, maintaining of fences, pruning of trees and weeding. After one year, cut-and-carry of grass for stall-feeding can be partly practiced, which is of economic benefit to the farmers. Rehabilitation normally takes about 7-10 years depending on the level of degradation and intensity of management. Land use is limited to selective cutting of trees, collection of dead wood and cut-and-carry of grass for livestock fodder. On individually owned enclosures land users start cutting trees after three years (for eucalyptus) and after 7–8 years (for other trees), while on communal land farmers are allowed to collect dead wood after 3-–4 years, and the community decides about the use of trees.



Technical drawing

Rehabilitation of degraded land based on enclosure with live fence. Natural regeneration of vegetative cover is supported by water harvesting structures and planting of nitrogen-fixing/multipurpose shrubs and trees as well as local grass species. On steeper slopes hillside terraces may be established.(Mats Gurtner)

5.1.2. Reforestation and/or afforestation

Reforestation refers to "the establishment of trees on land that has been cleared of forest within the relatively recent past." Operational forestry definitions of reforestation often include the planting of forests on lands which have, historically contained forests but are converted to some other use. Reforestation may include self-regeneration after harvesting. These areas have to be reforested artificially (usually within 3 -8 years) or with methods of natural regeneration (usually within 8-11 years). ***Afforestation* and *reforestation*** both refer to establishment of trees on non-treed land. Reforestation refers to establishment of forest on land that had recent tree cover, whereas afforestation refers to land that has been without forest for much longer.

According to FAO the term forest plantation includes all forests established by planting or seeding in the process of afforestation and reforestation. It relates to indigenous and introduced species, but must have a minimum area of 0.5 ha, a minimum crown cover of 10% and a potential minimum height of 5 m at maturity. Young natural stands and all plantations, which have yet to reach a crown density of 10% or tree height of 5 meters, are included under forest.

5.2. Soil restoration

Soil restoration (SR) is the technique of enhancing compacted soils to improve their porosity and nutrient retention. It includes biological (worms) and mechanical aeration, mechanical loosening (tilling), planting dense vegetation, and applying soil amendments. Healthy and fertile soil is the foundation for land productivity. Plants obtain nutrients from two natural sources: organic matter and minerals. Reduced soil fertility undermines the production of food, fodder, fuel and fiber. Soil organic matter, nutrients and soil structure are the main factors influencing soil fertility. Soil organic matter is a key to soil fertility. Organic matter includes any plant or animal material that returns to the soil and goes through the decomposition cycle. Soil organic matter (SOM) is a revolving nutrient fund: it contains all of the essential plant nutrients, and it helps to absorb and hold nutrients in an available form. Soil organic matter has multiple benefits; it is also fundamental for good soil structure through the binding of soil particles, for water holding capacity, and it provides a habitat for soil organisms. Soil texture also influences soil fertility. The presence of clay particles influences the soil's ability to hold nutrients. sandy soils usually have a lower nutrient holding capacity than clay soils, and hence need particular attention in terms of soil fertility management.

Declining soil fertility: The reason for a decline in SOM and the closely linked nutrient content is simply that the biomass and nutrient cycle is not sustained, meaning more material in the form of soil organic matter and / or nutrients (especially the macro-nutrients of nitrogen, phosphorous and potassium) leaves the system than is replenished.

This results from various causes:

- ✓ removal of crop products and residues (plant biomass),
- ✓ loss through soil erosion,
- ✓ leaching of nutrients (below the rooting depth),
- ✓ volatisation of nutrients (e.g. nitrogen),
- ✓ Accelerated mineralization of SOM through tillage.

The gains or replenishments are derived from residues of plants grown or nutrient accumulation (e.g. nitrogen fixing), external input of organic matter, manure and fertilizer, and nutrients through the weathering and formation of the soil.

Soil fertility can improve through:

Maintain or improve a balanced SOM–nutrient cycle, meaning that net losses should be eliminated and organic matter and / or nutrients added to stabilize or improve the soil fertility. Replenishment of soil nutrients is a major challenge. Replenishment and reduced loss of soil nutrients can be achieved through the following options:

1. **Improved fallow-systems:** The deliberate planting of fast-growing species - usually leguminous - into a fallow for rapid replenishment of soil fertility.
2. **Residue management:** A practice that ideally leaves 30% or more of the soil surface covered with crop residues after harvest. It requires residue from the previous crop as the main resource, it also helps reducing erosion, improving water infiltration and moisture conservation.
3. **Application of improved compost and manure:** Compost (mainly from plant residues) and manure (from domestic livestock) help to close the nutrient cycle by ensuring that these do not become losses to the system.
4. **Tapping nutrients:** This takes place through the roots of trees and other perennial plants when mixed with annual crops (e.g. in agroforestry systems). Trees act as nutrient pumps: that is they take up nutrients from the deep subsoil below the rooting depth of annual crops and return them to the topsoil in the form of mulch and litter. This enhances the availability of nutrients for annual crops.
5. **Application of inorganic fertilizer:** Inorganic fertilizers are derived from synthetic chemicals and / or minerals.
6. **Minimum soil disturbance:** Tillage systems with minimum soil disturbance such as reduced or zero tillage systems leave more biological surface residues, provide environments for enhanced soil biotic activity, and maintain more intact and interconnected pores and better soil aggregates, which are able to withstand raindrop impact (and thus reduce splash erosion). Water can infiltrate more readily and rapidly into the soil with reduced tillage, and this also helps protect the soil from erosion.

5.3. Wetland Rehabilitation

A wetland is a land area that is saturated with water, either permanently or seasonally. The return of a wetland and its functions to a close approximation of its original condition as it existed prior to disturbance on a former or degraded wetland site. Wetland rehabilitation means reestablishment of important missing or altered processes, habitats, concentrations, and species etc. Wetland rehabilitation restores to a wetland ecosystem to a condition that is functionally very similar to the pre-disturbance condition, but the wetland ecosystem will not be exactly as before (e.g., different biological species composition).

One of the most important aspects of managing a wetland is to repair damage from poor land use. The worst damage anyone can inflict on a wetland is to drain it for the production of pastures and crops. Other impacts on a wetland include overgrazing, excess cattle trampling and the wrong burning regime. Mismanagement of a wetland results in erosion, especially in the form of head-cuts. Channels and head-cuts essentially drain the wetland, dry it out and destroy it. They also increase the amount of sediment in the water thereby decreasing water quality. Other major wetland problems are the removal of stream bank vegetation, invasion by alien plant species and flooding because of land disturbances in the upper catchment. Wetlands are areas where water flow is slowed and sediment is captured. Where high erosion occurs more sediment is removed from the wetland than what is captured. Erosion occurs where there is a disturbance of soil or vegetation. Erosion in wetlands leads to deep gullies which drain the water rapidly; this reduces the benefits of the wetland.

Methods of rehabilitating wetlands:

- Blocking drainage channels that drain water from or divert polluted water to the wetland, with gabions or earthen plugs;
- Placing plugs in gullies, to help with bank and soil stabilization ;
- Fencing off sensitive areas to keep grazers out and fence off areas that have been disturbed and need time for vegetation to re-establish;
- Planting of vegetation to stabilize the soil;
- Filling in and compacting gullies with soil from other areas;
- Plug channels to restore or create wetlands. These can also be used to stabilize and raise the channel floors, thereby reducing velocity;
- Cement structures such as a cement head cut repair. This assists in reducing water velocity and helps reduce erosion and contain the head cut.
- Gabion structures which assist in bank and soil stabilization, reducing erosion and decreasing the speed of water flow. They also provide an area for vegetation to establish.

- Insertion of grass bales, these help bind soil and slow the rate at which water travels. The slower the water flow, the lower the erosive power of water. Binding and stabilizing soil prevents the soil from being washed downstream.

5.4. Monitoring and evaluating of rehabilitation practices

Monitoring and evaluation are providers to work towards providing the best care possible, with the available resources, methods and skills. Monitoring is used to describe systematic, continuous assessment of progress to inform managers and other stakeholders. As it is conducted regularly and is ongoing, there is an internal element. The purpose is to help identify goals, problem areas, progress towards achieving results and to initiate change. It may be performed at the level of the individual, programme or local community. The information collected includes inputs and outputs of the programme and the processes employed. The information obtained from monitoring can inform and strengthen an evaluation and form an essential basis for establishing efficacy and effectiveness. Evaluation focuses on the outcomes from a programme and aims to objectively assess progress and the achievement of results towards an agreed goal or to answer certain questions and provide guidance to decision-makers. Evaluation is usually conducted on a one off‟ basis. The desire for objectivity means evaluation often has an external element and so is typically conducted by people or organizations external to the programme, including funding agencies and international researchers.

5.4.1. Natural regeneration

Natural regeneration relies on older trees left on the land to provide seed to regenerate the site. This practice can only be employed if the site has not yet been harvested. Plans are then made for harvesting the present forest stand and leaving some trees to provide the seed. Mostly pine stands grow best where all trees are of the same age and receive the same amount of sunlight. Therefore, once the seedlings are established the large seed trees must be removed.

Methods of natural regeneration

A. Natural regeneration (NR) from seed

When regeneration obtained from seed forms a crop, it is called a seedling crop. It is neither planted nor of coppice or root-sucker origin but originating in situ from natural regeneration. When this seedling crop grows into a forest, it is called a high forest. NR from seed depends on the followings:

1) Seed Production: The most important consideration for natural regeneration from seed is the production of adequate amount of fertile seeds by the trees of the area or in the vicinity. The production of seed depends on the following: species, age of trees, and size of crown, climate, and other external factors.

2) **Seed Dispersal:** The seed produced by the trees is dispersed by the agency of wind, water, gravity, birds and animals. Some examples of seed dispersal by various agencies are given below:

- Wind: Conifers, Acer, Betula, Populus, Alnus, Salix, Terminalia, Dalbergia, Acacia, Adina , Bombax, etc.
- Water: Most mangrove species, Dalbergia, Teak, etc.
- Birds: Prunus, Mulberry, Diospyrus, etc.
- Animals: Acaica arabica, Prosopssis juliflora, Zizyphus, Anthocephallus, etc.
- Gravity: Oak, Juglans, Asculus, etc.

3) **Seed Germination**: After dispersal, insects, birds and rodents destroy a lot of seeds. The others germinate provided they are deposited on suitable soil. Germination of seeds depends upon several internal and external factors listed below:

- **Internal Factors:** Permeability to water, permeability to O_2, development of Embryo, viability of seeds, size of seeds, germination capacity, germination energy
- **External factors:** Moisture, air, temperature, light, seed Bed.

4) **Seedling Establishment:** Even if germination is good, it does not mean that natural regeneration would be good because a large number of seedlings die at the end of rains or as a result of frost during winter or drought during summer. In addition, there may be other factors such as weeds, grazing, fire, which may kill the seedlings. Thus, establishment is defined as the development of new crop naturally or assisted' to a stage when the young regeneration natural or artificial' is considered safe from normal adverse influences and no longer needs special protection or tending operation other than cleaning, thinning and pruning.

The following factors affect establishment of seedlings:

- Development of roots
- Soil conditions – Moisture, Aeration, Nutrients
- Light
- Other Climatic factors- high or low tempeture
- Rainfall
- Slash erosion
- Condition of grasses and other competing weeds
- Grazing, browsing and fire
- Composition of the crop

B. Natural regeneration from vegetative parts

When regeneration obtained by coppice forms a crop, it is called coppice crop and when it develops into a forest, it is called coppice forest to differentiate it from the high forest.

Natural regeneration by coppice can be obtained either by:

1) Seedling coppice: Coppice shoots arising from the base of seedlings that have been cut or burnt back. This method of obtaining natural regeneration is used for cutting back woody shoots and established reproduction which is not making any progress so that they may produce vigorous shoots and soon develop into saplings.

2) Stool coppice: Coppice arising from the stool or a living stump of a tree is called stool coppice. In this method, regeneration is obtained from the shoots arising from the adventitious buds of the stump of felled trees. The coppice shoots generally arise either from near the base of the stump or from its top. The shoots arising from near the top of the stump are liable to be damaged by the rotting of the upper portion of the stump as well as by wind, etc.

Advantage and disadvantage of natural regeneration

Advantages

- The initial costs of establishing a forest stand may be lower especially if site preparation is not necessary.
- Less heavy equipment and labor is required.
- The seedling has a naturally shaped root system unlike seedlings which have been grown in a nursery.

- Chance of tip moth damage is reduced (Beaufait and others 1984).
- For aesthetic reasons, the landowner may prefer to see a forest stand which is unevenly and naturally spaced versus a stand which is in rows.

Disadvantages

- A seed crop must be available and seed dispersal must be timed correctly with site preparation so that a suitable seedbed is available for the seed germination.
- Moisture in the soil is necessary for the seeds to germinate; exceptionally dry years or sites may result in poor germination or seedling mortality.
- Insects and other small seed-eating animals may consume all or most of the seed.
- Competing vegetation may be a problem for survival and growth for a longer time period than with planting because seedlings are smaller or seed may not be disseminated in the first year.

5.4.2. Soil Seed Bank

Soil seed banks include all living seeds in a soil profile, including those on the soil surface. In the beginning, Soil seed banks are also composed of dispersal units, which are seeds or fruits surrounded by structures serving for dispersal and sometimes contain other plant parts such as bracts or stems. Over time, the dispersal structures, as well as seed coats, can decompose, leaving only germination units. For example, Ranunculus arvensishas a thick seed coat and spikes which both decompose after burial in soil after a few years, leaving coatless seeds (A. Saatkamp, 2009, unpublished data). Soil seed banks resemble other biological reservoirs, such as invertebrate eggs, tubercles and bulb banks, spores of non-spermatophyte plants and fungi, or seeds retained on mother plants (serotiny). Soil seed banks vary much according to seed proximity, seed persistence and physiological state. Living seeds have been found in or on the soil for different durations, different seasons, at different depths, in different quantities and in different states of dormancy or procession to germination. Seeds in the soil seed bank may occur in or on the soil, but in many situations, there is continuity between seeds at the surface, partly buried and completely buried seeds. Plants differ in the duration their seeds remain in the soil and even within a species and among seeds of the same cohort there is variability in the time they spend in the soil seed bank.

Soil seed bank types

- Viable seeds present for less than 1 year
- Persistent seed banks for species with viable seeds that remain for more than 1 year. Persistent soil seed banks can be subdivided further into short-term persistent for seeds that are detectable for more than 1 but less than 5 years, and long-term persistent seed banks that are present for more than 5 years.

5.4.3. Bio-physical indicators

Biophysical indicators are tools that can be used to define resource status. Soil quality indicators are measurable properties or characteristics which provide information about the ability of the soil to provide essential environmental services. Those attributes most sensitive to management practices or land use changes are the most adequate as indicators. A wide range of physical, chemical and biological properties are available to be measured on a routine basis, but due to the impossibility of considering them all, it is necessary to make a selection.

Bio-physical Indicators useful for monitoring and evaluation of rehabilitation practices can be explained

1. Physical properties reflect limitation for the development of roots, seedling emergence, infiltration, water retention or movement of fauna.
2. The chemical condition affects the soil–plant relations, water quality, buffering capacity, availability of nutrients and contaminants.
3. Biological indicators are more sensitive and rapidly respond to perturbations and changes in land use; soil organisms, in addition, play a direct role in the ecosystems processes mainly in nutrient recycling and soil aggregation.

Chapter 6. Sustainable land management (SLM)

6.1. SLM Concept and progress

Land degradation, resulting from unsustainable land management practices, is a threat to the environment, as well as to livelihoods, where the majority of people directly depend on agricultural production. There is a potentially devastating downward spiral of overexploitation and degradation, enhanced by the negative impacts of climate change - leading in turn to reduced availability of natural resources and declining productivity: this jeopardizes food security and increases poverty. Sustainable land management (SLM) is, helping to increase average productivity, reducing seasonal fluctuations in yields, and underpinning diversified production and improved incomes. Sustainable land management is simply about people looking after the land for the present and for the future.

The main objective of SLM is thus to integrate people's coexistence with nature over the long-term, so that the provisioning, regulating, cultural and supporting services of ecosystems are ensured. This means SLM has to focus on increasing productivity of agro-ecosystems while adapting to the socio-economic context, improving resilience to environmental variability, including climate change and at the same time preventing degradation of natural resources.

SLM thus seeks to increase production including traditional and innovative systems and to improve resilience to food insecurity, land degradation, loss of biodiversity, drought and climate change. Sustainable Land Management has been 'the adoption of land use systems that, through appropriate management practices, enables land users to maximize the economic and social benefits from the land while maintaining or enhancing the ecological support functions of the land resources.

SLM includes management of soil, water, vegetation and animal resources. It also includes ecological, economic and socio-cultural dimensions. These three are not separate: in reality they are interconnected. They are also referred to as the **'3 Es'** of sustainable development - Equality, Economy, and Ecology. *Ecologically*, SLM technologies – in all their diversity –effectively combat land degradation. But a majority of agricultural land is still not sufficiently protected, and SLM needs to spread further. *Socially*, SLM helps secure sustainable livelihoods by maintaining or increasing soil productivity, thus improving food security and reducing poverty, both at household and national levels. *Economically*, SLM pays back investments made by land users, communities or governments. Agricultural production is safeguarded and enhanced for small-scale subsistence and large-scale commercial farmers alike, as well as for livestock keepers. Furthermore, the considerable offsite benefits from SLM can often be an economic justification in themselves.

Indicators of sustainable land management are necessary to monitor progress towards the goal of sustainability. These are required for use by scientists, program planners and policy makers to monitor the condition and trends in use of land and water resources, and the performance of agricultural and non-agricultural programs and policies. Although most indicators have to be "fitted" to the agro-environments and the land uses being considered, the following indicators are emerging as possible international standards for evaluation and monitoring of sustainable land management.

- Crop Yield (trend and variability)
- Nutrient Balance
- Maintenance of Soil Cover
- Soil Quality/Quantity
- Water Quality/Quantity
- Net Farm Profitability
- Participation (of farmers and society) in Conservation Practices

These indicators must be modified and tailored for specific uses in local environments, but they provide a good starting point for further investigation.

6.2. Sustainable land use and food security

1. Increased land productivity

The primary target of SLM is thus to increase land productivity, improve food security and also provide for other goods and services. There are two ways to achieve this:

(a) intensification and (b) diversification of land use.

a. Intensification: The last 50 years have witnessed major successes in global agriculture, largely as a result of the 'Green Revolution' which was based on improved crop varieties, synthetic fertilizers, pesticides, irrigation, and mechanization.

b. Diversification: This implies an enrichment of the production system related to species and varieties, land use types, and management practices. It includes an adjustment in farm enterprises in order to increase farm income or reduce income variability.

2. Water use efficiency

Water use efficiency is defined as the yield produced per unit of water. Optimal water use efficiency is attained through minimizing losses due to evaporation, runoff or drainage. In irrigation schemes, conveyance and distribution efficiency addresses water losses from source to point of application in the field. Often the term water productivity is used: this means growing more food or gaining more benefits with less water.

6.3. Barriers to Sustainable Land Management

Continuing land degradation is an important indicator of the existence of barriers that prevent countries from implementing sustainable land management. Often, the underlying causes of land degradation are complex, and solutions require a systemic and systematic approach. The challenge for policymakers is to make informed decisions about the use of natural resources without jeopardizing the resilience of the ecosystems. The major barriers in sustainable land management are explained here as following;

a. Institutional and Governance Barriers

A developing country's commitment to combating land degradation is frequently undermined by limited individual, institutional, and systemic capacity. At the national and regional levels, government institutions and ministries often lack personnel with technical or policy skills. At the same time, inter-institutional coordination and cooperation are generally competitive or non-existent. Agricultural and rural development infrastructures are often divided by sectors, and land degradation issues are not appropriately incorporated in decision making. Extension services, the link between the national and local levels-often suffer from budgetary cuts and low capacities, which affect their ability to provide the necessary services to the land users. In some developing countries, legislation is based on top-down command and control regulations that rely on compliance and enforcement. In others, the government's inability to enforce the law properly often leads to perverse behaviour by local land users. In these cases, laws and regulations are often poorly understood, ineffectively enforced, and subject to varying interpretations.

b. Economic and Financial Barriers

Many developing countries, especially least developed countries (LDCs) and Small Island Developing States (SIDS), lack the financial resources to change land management policies and practices. With insufficient budgetary allocations, the goal of sustainable land management remains elusive.

c. Social and Behavioural Barriers

People can be a major asset in reversing land degradation if they are healthy, politically motivated, and economically empowered to care for the land. Subsistence agriculture, poverty, and illiteracy are important causes of land and environmental degradation. Some countries are relying on environmental education as an instrument to halt environmental degradation in the long run. These programs provide opportunities to introduce linkages among population dynamics, land use change, and environmental impact.

d. Technological and Knowledge Barriers

At the local level, the stakeholders' knowledge of sustainable land management practices is often limited to traditional techniques and knowledge that has been transferred through generations. However, what might have been a sustainable land use practice in the past may not be viable anymore. New technologies and information on how to adapt traditional technologies to the new challenges are key priorities. For example, many developing country farmers live and work in isolation, without access to data and information that are essential for choosing the right crop variety, estimating the right amount of irrigation water, and preparing for a severe drought period or a potential natural disaster.

6.4.Strategic options

6.4.1. Land tenure

Land tenure is the relationship, whether legally or customarily defined, among people, as individuals or groups, with respect to land. Land tenure is an institution, i.e., rules invented by societies to regulate behaviour. Rules of tenure define how property rights to land are to be allocated within societies. They define how access is granted to rights to use, control, and transfer land, as well as associated responsibilities and restraints. In simple terms, land tenure systems determine who can use what resources for how long, and under what conditions.

Land tenure is an important part of social, political and economic structures. It is multi-dimensional, bringing into play social, technical, economic, institutional, legal and political aspects that are often ignored but must be taken into account. Land tenure relationships may be well-defined and enforceable in a formal court of law or through customary structures in a community. Alternatively, they may be relatively poorly defined with ambiguities open to exploitation.

Land tenure thus constitutes a web of intersecting interests. These include:

- Overriding interests: when a sovereign power (e.g., a nation or community has the powers to allocate or reallocate land through expropriation, etc.)
- Overlapping interests: when several parties are allocated different rights to the same parcel of land (e.g., one party may have lease rights, another may have a right of way, etc.)
- Complementary interests: when different parties share the same interest in the same parcel of land (e.g., when members of a community share common rights to grazing land, etc.)
- Competing interests: when different parties contest the same interests in the same parcel (e.g., when two parties independently claim rights to exclusive use of a parcel of agricultural land. Land disputes arise from competing claims.)

Land tenure is often categorized as:

- ***Private:*** the assignment of rights to a private party who may be an individual, a married couple, a group of people, or a corporate body such as a commercial entity or non-profit organization. For example, within a community, individual families may have exclusive rights to residential parcels, agricultural parcels and certain trees. Other members of the community can be excluded from using these resources without the consent of those who hold the rights.
- ***Communal***: a right of commons may exist within a community where each member has a right to use independently the holdings of the community. For example, members of a community may have the right to graze cattle on a common pasture.
- ***Open access***: specific rights are not assigned to anyone and no-one can be excluded. This typically includes marine tenure where access to the high seas is generally open to anyone; it may include rangelands, forests, etc, where there may be free access to the

resources for all. (An important difference between open access and communal systems is that under communal system non-members of the community are excluded from using the common areas.)

- ***State***: property rights are assigned to some authority in the public sector. For example, in some countries, forest lands may fall under the mandate of the state, whether at a central or decentralized level of government.

In practice, most forms of holdings may be found within a given society, for example, common grazing rights, private residential and agricultural holdings, and state ownership of forests. Customary tenure typically includes communal rights to pastures and exclusive private rights to agricultural and residential parcels.

Examples of rights

- A right to use the land.
- A right to exclude unauthorized people from using the land.
- A right to control how land will be used.
- A right to derive income from the land.
- A right to protect from illegal expropriation of the land.
- A right to transmit the rights to the land to one's successors, (i.e., a right held by descendents to inherit the land).
- A right to alienate all rights to the entire holding (e.g., through sale), or to a portion of the holding (e.g., by subdividing it).
- A right to alienate only a portion of the rights, e.g., through a lease.
- A residuary right to the land, i.e., when partially alienated rights lapse (such as when a lease expires), those rights revert to the person who alienated them.
- A right to enjoy the property rights for an indeterminate length of time, i.e., rights might not terminate at a specific date but can last in perpetuity.
- A duty not to use the land in a way that is harmful to other members of society, (i.e., the right is held by those who do not hold the right to use the land).
- A duty to surrender the rights to the land when they are taken away through a lawful action, (e.g., in a case of insolvency where the right is held by the creditors, or in the case of default on tax payments where the right is held by the state).

At times it may be useful to simplify the representation of property rights by identifying:

- ***Use rights:*** rights to use the land for grazing, growing subsistence crops, gathering minor forestry products, etc.
- ***Control rights:*** rights to make decisions how the land should be used including deciding what crops should be planted, and to benefit financially from the sale of crops, etc.
- ***Transfer rights:*** right to sell or mortgage the land, to convey the land to others through intra-community reallocations, to transmit the land to heirs through inheritance, and to reallocate use and control rights.

Very often, the poor in a community have only use rights. A woman, for example, may have the right to use some land to grow crops to feed the family, while her husband may collect the profits from selling any crops at the market. While such simplifications can be useful, it should be noted that the exact manner in which rights to land are actually distributed and enjoyed can be very complex. Therefore, usually the communal, open access, and state form of land (and resources in the land) rights result in unsustainable resource benefit. The poor and women are usually marginalized.

Improving land tenure and users' rights is a key entry point:

1. Providing basic individual and collective security of resource use
2. Clarifying tenure and user rights to private and communal land, including locally negotiated tenure systems, regulations and land use.
3. Looking for pragmatic and equitable solutions in cases where land tenure reforms are ongoing
4. Increasing land title registration and linking this to land use planning through a cadastral system
5. promotion of women's land rights in land registration and customary land tenure systems

6.4.2. Land administration

Land administration is the way in which the rules of land tenure are applied and made operational. Land administration, whether formal or informal, comprises an extensive range of systems and processes to administer:

- ***Land rights:*** the allocation of rights in land; the delimitation of boundaries of parcels for which the rights are allocated; the transfer from one party to another through sale, lease, loan, gift or inheritance; and the adjudication of doubts and disputes regarding rights and parcel boundaries.

- ***Land-use regulation*****:** land-use planning and enforcement and the adjudication of land use conflicts.
- ***Land valuation and taxation:*** the gathering of revenues through forms of land valuation and taxation, and the adjudication of land valuation and taxation disputes.

Information on land, people, and their rights is fundamental to effective land administration since rights to land do not exist in a physical form and they have to be represented in some way. In a formal legal setting, information on rights, whether held by individuals, families, communities, the state, or commercial and other organizations, is often recorded in some form of land registration and cadastre system. In a customary tenure environment, information may be held, unwritten, within a community through collective memory and the use of witnesses. In a number of communities, those holding informal rights may have "informal proofs" of rights, i.e., documents accepted by the community but not by the formal state administration.

An ***enforcement or protection component*** is essential to effective land administration since rights to land are valuable when claims to them can be enforced. Such a component allows a person's recognized rights to be protected against the acts of others. This protection may come from the state or the community through social consensus as described below in the section on "Tenure Security". A stable land tenure regime is one in which the results of protective actions are relatively easy to forecast. In a formal legal setting, rights may be enforced through the system of courts, tribunals, etc. In a customary tenure environment, rights may be enforced through customary leaders. In both cases, people may be induced to recognise the rights of others through informal mechanisms such as community pressures. People who know their rights, and know what to do if those rights are infringed, are more able to protect their rights than those who are less knowledgeable. Land administration is implemented through ***sets of procedures*** to manage information on rights and their protection, such as:

- Procedures for land rights include defining how rights can be transferred from one party to another through sale, lease, loan, gift and inheritance.
- Procedures for land use regulation include defining the way in which land use controls are to be planned and enforced.

- Procedures for land valuation and taxation include defining methodologies for valuing and taxing land.

Efficient procedures allow transactions to be completed quickly, inexpensively, and transparently. However, in many parts of the world, formal land administration procedures are time-consuming, bureaucratically cumbersome and expensive, and are frequently non-transparent, inaccessible to much of the rural population, and are handled in languages and forms that people do not understand. In such cases, high transaction costs may result in transfers and other dealings taking place off-the-record or informally.

Finally, land administration requires actors to implement the procedures. In customary tenure regimes, the customary leaders may play the principal role in land administration, for example in allocating rights and resolving disputes. In a more formal setting, land administration agencies may include land registries, land surveying, urban and rural planning, and land valuation and taxation, as well as the court systems. Where customary tenure has been recognised by the State, functional linkages are being developed between government and customary land administration bodies.

Formalisation of the administration of land rights has been promoted as a pre-requisite for economic development. Perceived benefits include increased tenure security and improved access to credit, thereby providing the incentive and ability for farmers to invest in making improvements to the land. Formal administration is also proposed as a means to facilitate a land market, allowing land to move towards its "highest and best use".

These claims are disputed by others who argue that too often, the flawed design and implementation of projects to formalise property rights have resulted in a reduction of security by concentrating rights to a parcel in the hands of an individual, and neglecting the claims of others, particularly women and other vulnerable groups, who hold partial or common rights. Similarly, it is argued by some that access to credit may not improve with formalisation since many banks are unlikely to accept agricultural land as collateral against loans.

As a result, it has been suggested that formal registration of individual property rights should be considered only in areas of high population density, where customary tenure systems and dispute resolution systems are weak or absent, or where there have been other major disruptions to customary land holdings. However, even where these conditions do not exist, there is growing interest in several countries to formalise the rights of communities to protect them against encroachment from outsiders (e.g., commercial farming operations and even the State). In such cases, the community boundaries are defined, and title to the land is registered in the name of the community. It is then left to the community to undertake its own land administration, including the allocation of rights to land within its boundaries.

In many countries, formal and informal land administration co-exist when legal records do not replace customary rights, or when newly created informal rights come into existence. Tensions can exist between *de jure* and *defacto* rights to land. Discrepancies between formal and informal or customary versions of tenure holdings create ambiguities to be exploited. In some countries where formal land administration systems do not function well, different titles may be issued by the State for the same parcel of land. This complicates the legal status of the land since it gives rise to competing claims. The mere act of establishing and documenting land boundaries and titles is not enough; it has to be done in a way that does not make the situation worse. The role of local communities in investigating claims is crucial as they have the knowledge of the local tenure arrangements.

6.4.3. Socio-economic aspects

In countries where the majority of the population lives below the poverty line, soil and water conservation measures must be accompanied by measures to alleviate poverty in order that soil and water conservation may be successful and the goals of sustainable land management can be achieved. Poverty is an essential cause of mismanagement and resulting degradation of natural resources in many places. An increasing degradation of natural resources in turn aggravates poverty. Sustainable land management addresses all aspects of land degradation vicious circle. Poverty reduction involves several sectors in which suitable measures are to be implemented: measures to encourage education and health (including measures to combat HIV/AIDS), for instance. Participation of local people in planning, implementing and monitoring of these actions is decisive for sustainable outcomes. The economic interests and opportunities of the land resource users are to be considered and improved in all intended measures. Costs of all measures must lie within the available budget of the project. Furthermore, the measures have to be economically viable. Also crucial in sustainable land management is to strengthen gender and minority representation in institutions and decision-making processes.

6.4.4. Policy mechanism

Government policies, programs and institutions may influence livelihood strategies and land management and their implications for productivity, sustainability, and household incomes at many levels. Macroeconomic, trade, and market liberalization policies will affect the relative prices of commodities and inputs in general throughout a nation. Agricultural research policies affect the types of technologies that are available and suitable to farmers in a particular agro-ecological region. Infrastructure development, agricultural extension, conservation technical assistance programs, land tenure policies and rural credit and savings programs affect awareness, opportunities, or constraints at the village and household level.

Policies or programs may seek to promote particular livelihood strategies (e.g. food crop production), or may seek to address constraints arising within a given livelihood strategy (e.g. credit needs arising in cash crop production). Programs may attempt to address sustainable land management approaches directly, for example by promoting particular soil fertility management practices. Policies and programs may also be designed to affect development outcomes directly, through direct management of land by the government, or through nutrition or income enhancement programs. Much public action aimed at improving land management focuses on influencing household adoption of particular technologies. Yet this may be ineffective if the technologies are not suited to the livelihood strategies that have comparative advantage in a given location. It may be more effective in many cases to first focus on the larger development strategies for particular livelihood strategies, before focusing too much on particular land management technologies.

Policies in support of SLM are needed to promote and address the complexity of sustainable land use, in particular policies providing incentives for SLM investments at household, community, regional and national level. Policies must address the root causes of land degradation, low productivity and food insecurity and simultaneously establish socially acceptable mechanisms for encouragement or enforcement.

Improvement of national policy frameworks: There are clear opportunities to improve national policy frameworks in support of SLM and to overcome bottlenecks that hinder the spread of SLM:

1. Creating an enabling institutional environment:
2. strengthening institutional capacity
3. clarifying roles and responsibilities
4. enhancing collaboration with land users
5. furthering collaboration and networking between institutions
6. strengthening and integrating farmer-extension-research linkages
7. securing finances (budgetary provision for extension)

6.4.5. Agro-ecological components

6.4.6. Other enabling environment