SOIL DEGRADATION

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SOIL DEGRADATION

1 INTRODUCTION

Soil degradation is on the increase worldwide, especially in the countries within the tropics. Mismanagement of arable areas by farmers and grazing areas by livestock owners is one of the major causes of soil degradation. More sustainable management of lands would reduce environmental pressures. Conservation tillage, i.e. reduced or no tillage, is the key to sustainable arable land management as it protects the soil resources, increases the efficiency of water use and, of special importance in semi-arid areas, reduces the effects of droughts(FAO 1999).

Land/soil degradation can either be as a result of natural hazards or due to unsuitable land use and inappropriate land management practices. Natural hazards include land topography and climatic factors such as steep slopes, frequent floods and tornadoes, blowing of high velocity wind, rains of high intensity, strong leaching in humid regions and drought conditions in dry regions. Deforestation of fragile land, over cutting of vegetation, shifting cultivation, overgrazing, unbalanced fertilizer use and non-adoption of soil conservation management practices, over-pumping of ground water (in excess of capacity for recharge) are some of the factors which comes under human intervention resulting in soil erosion. Causes of soil erosion have a direct bearing on imputing relevant cost in SEEA.

The United Nations Environment Programme (UNEP) formulated a project proposal for Global Assessment of the Status of Human-Induced Soil Degradation (GLASOD[1]) in 1987 which developed methodologies to create soil and terrain databases. The main objective of the GLASOD project was to strengthen global awareness of policy-makers and decision makers of the dangers resulting from inappropriate land and soil management. The project also aimed to provide information (in the form of digitized maps) on soil and terrain resources to the potential users in non-technical terms. Since then (1991) important regional inventories on land degradation were undertaken, notably in South and Southeast Asia(in close cooperation with national institutes in 17 Asian countries and with technical and financial support from UNEP and FAO) Southeast Asia (UNEP/ISRIC/FAO, 1996: ASSOD: Assessment of Soil Degradation in Southeast Asia) and for Eastern Europe (FAO/ISRIC,2000 :SOVEUR: Soil Vulnerability to Pollution in Eastern Europe, FAO Land and Water Digital Media Series # 9 in preparation). In these surveys the GLASOD methodology has been refined. You can have a look at the ISRIC website for more details on both: http://www.isric.nl/ASSOD.htm and http://www.isric.nl/SOVEUR.htm

The GLASOD map does not, however, assess the vulnerability of land resources to the soil degradation process but the status of degradation which assists policy-makers and resource managers to identify priority areas of intervention. To assess soil vulnerability a comprehensive information system on soil and terrain resources is needed. For this purpose,

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[1] This was achieved with the help of more than 200 soil scientists and environmental experts worldwide. The project also received active advice from the FAO and the International Society of Soil Science (ISSS). Regional cooperators were asked to delineate on a standard topographic base map (derived from the world map of the Institut Geographique National) map units showing a certain homogeneity of physiography, climate, vegetation, geology, soil and land use. Within each delineated map unit, soil degradation, its relative extent within the unit and the type of human intervention that has resulted in soil degradation during the post-war period were also indicated. The regional results were then generalized and compiled as a world map.

SOTER[2] was developed which is an internationally endorsed land resource information system that can store at different levels, detailed soil and terrain attributes in such a way, that these data can be assessed, combined, and updated immediately and can be easily analyzed from the point of view of potential land use, in relation to food requirements, environmental impact, and conservation.

2   TECHNOLOGICAL DEVELOPMENTS[3]

Over the last two decades the Land and Water Development Division (AGL) of the FAO has been at the forefront of the development of computer-based systems to analyse data and generate information to support decisions on various land and water issues. Separate soil and land and water systems have been developed for this purpose. A brief account of important work is given below

Agro-Ecological Zoning (AEZ) System : The main system for land resource assessment is the FAO's agro-ecological zoning (AEZ) methodology and supporting software packages for application at global, regional, national and subnational levels.

AEZ integrates various kinds of geo-referenced data sets in the database, which can include the following:

- topography;
- administrative boundaries;
- road/communications;
- towns and settlements;
- rivers/water bodies;
- geology;
- soil;
- physiography;
- landform;
- erosion;
- rainfall;
- temperature;
- moisture regime;
- watersheds;
- irrigable areas;
- land use/land cover and forest reserves;
- production systems
- crop requirements;
- agricultural inputs;
- crop statistics;
- markets;
- prices;
- population.

AEZ models are applied on the database to analyse potentials of land for various kinds of use. The AEZ models can be extended to include models for the calculation of length of growing period, irrigation requirements, crop biomass, land suitability and land productivity.

Multi-lingual Soil Database (SDBm) : Database tool useful for storage of primary soils information assembled at the national level, or data collected in a soil survey at the sub-national and local levels. SDBm data are used in the computerized AEZ land evaluation systems. It is useful to soil scientists, agricultural extension officials and environmental modellers.

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[2] The SOTER approach is the mapping of an area (SOTER units) with a distinctive, often repetitive pattern of land form, surface form, slope, parent material and soils. Each SOTER unit is linked through a Geographic Information System with a computerized database containing all available attributes on topography, land form and terrain, soil, climate, vegetation and land use. In this way each type of information or each combination of attributes can be displayed as a separate layer or overlay or in tabular form.

[3] Extracts from Information technology and decision support systems in an AGL Background Paper by J. Antoine, Soil Resources, Management and Conservation Service Land and Water Development Division, FAO, Rome, Italy. For further details, reference may be made to http://www.fao.org/waicent/FaoInfo/Agricult/AGL/agls/aglshome.htm

Soil And Terrain (SOTER) Database : SOTER is useful for storing soil and terrain data at the national and global scale in an easily accessible format for thematic mapping and monitoring of changes of soil and terrain resources and for AEZ evaluation of land resources potential for land use planning. It can be used by scientists, planners, decision-makers and policy makers. SOTER utilizes a Relational Database Management System (RDBMS) and Geographic Information System (GIS) to establish a World Soils and Terrain Database, containing digitized map units and their attribute data. SOTER uses a specific methodology and its own system for classification of terrain designed for universal application. SOTER has adopted the recently Revised FAO Soil Legend as a reference classification system for differentiating and characterizing its soil components.

Digitized Soil Map of the World (DSMW) : The Digital Soil Map of the World (DSMW) is the FAO's global soil database based on the paper FAO/UNESCO Soil Map of the World (scale 1:5,000,000). It consists of ten map sheets: Africa, North America, Central America, Europe, Central and Northeast Asia, Far East, Southeast Asia, and Oceania. DSMW contains two types of files: map files and derived soil properties files. The programs produce analyses of soil inventories, problem soils and fertility capability classification. Included are maps of soil units classified according to the World Soil Reference Base and topsoil distribution, which can used in teaching soil science. The database includes information on soil moisture storage capacity, soil drainage class and effective soil depth, useful for environmental studies.

FAO/ITC Land Use Database : To store information on land use for various purposes: assessing land production potentials, monitor land use changes and human impacts on the land, soil degradation and many other damaging effects at various scales. The FAO/ITC land use database is a PC program that stores information on individual land uses and production systems in terms of activities, inputs and benefits on the physical, social and economic environment. The program comprises 1) a data entry module containing collected land use data, defined land use classes, plus program settings and options for data entry and storage; 2) a query module that searches for land use data and classes on the basis of user-defined criteria 3) a glossary with numerous terms used to describe operations, inputs and land use types and classes. These are available in the form of multiple-choice lists, from which the user makes a selection.

ECOCROP 1 (Crop Environmental Requirements Database) : Ecocrop 1 can be used to identify suitable crop or tree species for a specified environment or for a defined use and to create a library of crop environmental requirements. Ecocrop 1 is a database that provides the optimum and minimum- maximum ranges of crop environmental requirements for various species. The database contains information on 1700 species that can be used to facilitate the comparison of 12-20 different environmental requirements across different groups of species, or across species of different use. The database includes arable crops, grasses, trees and some other plant species with special uses. The information has proven useful to gardeners, farmers, students, agricultural development and extension staff and land-use planners.

ECOCROP 2 (Crop Environmental Response Database) : Ecocrop 2 can be applied to obtain environmental response information for 20 crops of global importance, information for crop modelling including the facility to graph the responses and organize and compare crop response information. The users can enter their own data and use the software to graph the responses on the screen and to provides statistical output for crop modelling.

World Overview of Conservation Approaches and Technologies (WOCAT) : WOCAT is tool that aims at promoting improved decision making on land management and transfer of

appropriate technology through collection, analysis, presentation and dissemination of knowledge on soil and water conservation (SWC) worldwide. In particular, WOCAT can be used to identify options for overcoming land degradation problems. The WOCAT database will allow linkages with ECOCROP, Soil and AEZ data, and land use information. (World Overview of Conservation Approaches and Technologies, University of Bern, GTZ, FAO, 1999 FAO Land and Water Digital Media Series #3, FAO 1998) which is an overview and mapping of what is being done to counter land degradation. Web site at: http://www.fao.org/ag/agl/agll/wocat.htm

Database Tool for Integrated Plant Nutrition Systems (DTIPNS) : To provide researchers, extension officers and development workers in the area of plant nutrition management with numerical data and other relevant information on plant nutrient management practices, plant nutrient inputs, losses, and uptakes and response to plant nutrients under a range of conditions for selected countries. This information will allow the derivation of nutrient balance sheets and the economic and agronomic evaluation of alternative plant nutrient management practices, and so assist decision making on balanced, environmentally friendly plant nutrition practices at the farm level. FAO-IPNS contains data collected at the national and local level on the following variables:

1. Nutrient content of mineral, organic and biological sources of plant nutrients (including micronutrients).
2. Nutrient losses due to erosion and run-off, leaching, crop uptake, volatilization and denitrification.
3. Response curves to one or more nutrient sources under a range of conditions.
4. Descriptions of major crop rotations and plant nutrition practices of farmers in selected countries under a range of conditions.

ALES Expert System : ALES is a PC computer program to carry out land evaluations according to the method presented in the FAO Framework for Land Evaluation (FAO, 1976).   Such evaluations are location-specific, usually require many data, involve numerous repetitive calculations or references to tables and are tedious if many possibilities are to be compared. ALES is a useful tool that provides an automated procedure of evaluation to replace manual procedures that are time-consuming and error prone. ALES is not by itself an expert system, and does not contain knowledge about land and land use. It is a framework within which evaluators can express their own local knowledge. ALES can also be thought of as a model of expert judgement that is the codification in a constrained form of the inferences already present in the mind of the expert.

Aquastat Database : The AQUASTAT program has been launched in order to provide basic information on water resources and their use, in particular for agriculture and rural development, and produce country profiles on water resources development, with emphasis on irrigation and drainage. Aquastat mainly provides users interested in global or regional perspectives systematically organized and reliable information on water resources and water use existing in the countries for studies and analysis and action programs on sustainable use of water, such as irrigation potential studies and land productivity assessments and for monitoring water resources. The main quantified variables gathered in the AQUASTAT database are:

● renewable water resources (groundwater and surface water);
● wastewater production and treatment;

- non-conventional water sources;
- water withdrawal by sector;
- irrigation potential;
- irrigated areas, water control and irrigation techniques;
- origin of irrigation water;
- types of management for fully or partially controlled irrigation schemes;

The main quantified variables gathered in the AQUASTAT database (continue):

- number of beneficiaries;
- cost of irrigation and drainage development and operation and maintenance;
- irrigated and rainfed crops and yields;
- drained areas and drainage technologies;
- areas salinized by irrigation and flood protected areas;
- population affected by water-borne and water-related diseases.

Climatic Database (CLIMWAT) : CLIMWAT is a multi-purpose climatic database which was developed primarily for use in providing climate data inputs for the calculation of crop water requirements, irrigation supply and irrigation scheduling for various crops in combination with the program CROPWAT (see below). CLIMWAT is also useful in providing climatic data to AEZ land resources assessments. The CLIMWAT database has been originally compiled by the Agrometeorological Group of the FAO Research and Technology Development Division (SDR).

CROPWAT (a computer program for irrigation planning and management) : The program is meant as a practical tool to help both the Irrigation Engineer and Irrigation Agronomist to carry out standard calculations for design and management of irrigation schemes. It can further help in the development of recommendations for improved irrigation practices and the planning of irrigation schedules under varying water supply conditions. CROPWAT is a computer program for IBM-PC or compatibles. Its main functions are:

To calculate:	-	Reference evapotranspiration
	-	Crop water requirements
	-	Irrigation requirements
	-	Scheme water supply
To develop:	-	Irrigation schedules under various management conditions
To evaluate	-	Rainfed production and drought effects

SIMIS (Scheme Irrigation Management Information System) : When managing irrigation systems a tool is needed to facilitate the management tasks of irrigation systems. SIMIS can be used to provide timely and complete information for decisions with regard to the day-to-day management activities including water deliveries and other major issues such as accounting, crop production, control of maintenance, water fees and other relevant tasks.

If one follows the AEZ procedure, the first step would be to prepare a digitized land resource map. In this map, the land available for agriculture (including forestry) is indicated and agroclimatic information is superimposed to find out alternative economic activities by taking into account moisture availability, growing season, temperature, day

length and other site and soil factors. A possible composition of the data bank[4] which needs to be created for a comprehensive land use planning for agriculture is given below:

A. ATMOSPHERIC QUALITIES

A1   Atmospheric moisture supply: rainfall, length of growing season, evaporation, dew formation.

A2   Atmospheric energy for photosynthesis: temperature, day length, sunshine conditions.

A3   Atmospheric conditions for crop ripening, harvesting and land preparation: occurrence of dry spells.

C. COVER QUALITY

C1   Value of standing vegetation as "crop" such as timber.

C2   Value of standing vegetation as germ-plasm: biodiversity value (intra-specific variability and number of species).

C3   Value of standing vegetation as a protection against degradation of soil and catchment area.

C4   Value of standing vegetation as a regulator of local and regional climatic conditions.

C5   Regeneration capacity of the vegetation after complete removal.

C6   Value of standing vegetation as shelter for crops and cattle against adverse atmospheric influence.

C7   Hindrance of vegetation on introduction of crops and pastures: the land development cost.

C8   Incidence of above ground pests and vectors of diseases: health risk to humans and animals.

T. LAND SURFACE AND TERRAIN QUALITIES

T1   Surface receptivity as seedbed: the tilth condition.

T2   Surface treadability: the bearing capacity for cattle, machinery, etc.

T3   Surface limitations for the use of implements (stoniness, stickiness, the arability).

T4   Spatial regularity of soil and terrain pattern, determining size and shape of fields with a capacity for uniform management.

T5   Surface liability to deformation: the occurrence or hazard of wind and water erosion.

T6   Accessibility of the land: the degree of remoteness from means of transport.

T7   Surface water storage capacity of the terrain: the presence of potential of pounds, on-farm reservoirs, bunds, etc.

T8   Surface propensity to yield runoff water for local water harvesting or down stream water supply.

T9   Accumulation position of land: degree of fertility renewal or crop damage by overflow or overblow.

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[4] Planning for Sustainable Use of Land Resources: Towards a new approach, FAO Land and Water Bulletin 2 (1995).

S. SOIL PROFILE QUALITIES

S1   Physical soil fertility: the net moisture storage capacity in rootable zone.

S2   Physical soil toxicity: the presence or hazard of water logging in rootable zone.

S3   Chemical soil fertility: the availability of plant nutrients.

S4   Chemical soil toxicity: salinity or salinization hazard; excess of exchangeable sodium.

S5   Biological soil fertility: the N-fixation capacity of the soil biomass; and its capacity for soil organic matter turnover.

S6   Biological soil toxicity: the presence or hazard of soil-borne pests and diseases.

U. SUBSTRATUM OR UNDERGROUND QUALITIES

U1   Groundwater level and quality in relation to (irrigated) land use.

U2   Substratum potential for water storage (local use) and conductance (downstream use).

U3   Presence of unconfined freshwater acquires.

U4   Substratum (and soil profile) suitable for foundation works (buildings, roads, canals, etc.)

U5   Substratum (and soil profile) as source of construction materials.

U6   Substratum (and soil profile) as source of minerals.

3   CLASSIFICATION OF SOIL DEGRADATION

Among the land used for agriculture and forestry, soil is an important component. The intense and increased pressure on land leads to its degradation and pollution, which may result in a partial or complete loss of it's productive capacity. Soil degradation can be described as a process by which one or more of the potential ecological functions of the soil are harmed. These functions relate to bio-mass production (nutrient, air and water supply, root support for plants) to filtering, buffering, storage and transformation (e.g., water, nutrients, pollutants), and to biological habitat and gene reserve. Soil degradation is defined as a process that lowers the current and/or future capacity of the soil to produce goods and services. Two categories of a soil degradation process are recognised, viz., displacement of soil material (e.g., soil erosion by water forces or by wind forces) and *in situ* soil deterioration covering chemical or physical soil degradation. Classifications of soil degradation types, subtypes and symbols for use are given below. The relevant definitions are given in FAO (1994) and (Adapted from FAO/RAPA, 1992).

W:Water erosion
Wt: Loss topsoil
Wd Terrain deformation/mass movement
Wo Off-site effects
Wo reservoir sedimentation
Wof: flooding
Woc:Coral reef and seaweed destruction

E: Wind erosion
Et:Loss of topsoil
EdTerrain deformation
EoOver-blowing

C: Chemical deterioration
Cn:Loss of nutrients and/or organic matters
Cs:Salination
Ca:Acidification
Cp:Pollution
Ct:Acid sulphate soils
Ce:Eutrification

P:Physical deterioration
Pc:Compaction, sealing and crusting
Pw :Water- logging
Pa:Lowering of water table
Ps: Subsidence of organic soils
Po: Other physical activities such as mining and urbanistion

Erosion is a natural and continuous process. Soils are created through erosion of parent material and either local deposition or transport and deposition elsewhere. *Erosion*, is defined as the detachment or uptake, and transport over a certain distance of material of the upper layer of the earth crust by an agent, like water, wind or ice. This mass movement of soil particles, is part of the process of soil degradation. Before erosion takes effect, the degradation process often has started with qualitative changes in the soil, like loss of nutrients, loss of organic materials, reduced soil life and loss of soil structure.

There are three forms of erosion characteristic of degraded arid and semi-arid rangeland areas(FAO website,2000):
Sheet Erosion the most common form of erosion. Unprotected soil particles are loosened by trampling, through wind erosion and by the impact of rainfall. The soil particles are then transported by rainwater surface flow to the river and stream systems. Sheet erosion is characterised by a general lowering of the soil level, leaving raised pedestals where the root mass of the remaining vegetation protects it.
Wind erosion less common, but again takes place after vegetation has been lost and when soil particles are loosened. Early signs of wind erosion include deposition of sand particles around plants and micro-ripples on the surface of exposed areas. The final extreme is the classic sand desert dune structures.
Gully Erosion the most obvious and dramatic demonstration of erosion, although in most areas actually less significant in terms of total land degradation. Gully erosion rarely occurs without sheet erosion. The trigger for gullying can be the loss of vegetation in areas where the microtopography results in concentrated streamflow during the rains. They can also be triggered by erosion along livestock tracks, footpaths and road edges. The process can start with "rills" and end up with gullies that are tens of metres deep.

4   MEASUREMENT OF SOIL DEGRADATION

The effects of soil erosion are complex. Some of the impacts may appear to be reversible by suitable soil conservation programmes and improving cultivation practices, whereas there are other types of degradation which are irreversible. The latter type includes land lost by gulling, or cases of severe sheet erosion where the soil cover has been removed to a great extent. In cases where degradation is reversible it is generally difficult to assess the actual extent and impact of land degradation as farmers do convert their land to less demanding uses or increase the level of inputs.

Methodologies for prediction of soil erosion have been developed since the early thirties. This work was generally based on type of soil erosion. For example, conceptual work for universal soil erosion which predicts sheet and rill erosion by water was done by Cook (1936) which was finally updated by Wischmeier (1978). This method used rainfall erosion, soil erosion factor, length and steepness of the slope etc. to measure average annual soil loss. Similar work was done for measurement of soil erosion by wind (Woodruff, et al., 1965). However, a systematic effort to assess the nature and extent of land degradation at a regional or global scale was made only in the 90s. The most important studies on land degradation include the GLASOD mapping exercise by Oldeman, Hakkeling and Sombroek (1990) and a comparative study of drylands by Dregne and Chou (1992). Studies like GLASOD provide a global status which is generally based on qualitative expert estimates. In recent years some work (Parikh, Aguirre, etc.) has been done to assess the soil degradation on the basis of actual collection of data. Some of these methods have been illustrated in the following discussions by way of examples extracted from source references.

Despite being in arid and semi-arid areas the erosion is largely a result of infrequent but heavy rainfall events. Below, only soil degradation and erosion by water and wind will be discussed.

4.1 Water erosion

Water erosion depends on four factors: rainfall, soil type, slope gradient, and soil use/vegetation cover. Loss of soil structure becomes often most visible in encrustation of the soil. That is, the hardened topsoil seals off the underlying soil layers, and water - especially after a dry period - cannot enter the soil. The result is a superficial and eroding run-off. Encrustation may have various reasons: insufficient plant cover makes raindrops directly impound the soil; soils containing fine soil particles (silt) are more vulnerable; recent research has shown that the topsoil may become hydrophobic due to compounds leached from plants.
Three types are distinguished: sheet, rill and gully erosion. In sheet erosion, the top layer is more or less evenly removed. With rill erosion, a series of parallel superficial gullies is formed in the topsoil. Gully erosion is the formation of deep, disparate trenches, often in existing depressions. The last form of erosion is the most difficult to remedy, because of the amount of top (and deeper) soil removed.

4.2. Some methods to assess water erosion

a. Material load of rivers

 A simple way to get a general picture of the erosion rate is measuring the (suspended) *material load of rivers*.[5] By dividing the result by the watershed surface the mean erosion rate per surface unit is acquired. Measurements and computations can be made fairly quick, but offers a rather distorted picture of erosion, for several reasons:

1. Materials may also originate from the riverbed.
2. Soil particles may not reach the river, but may be deposited at the end of a slope or be deposited by the river.

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[5] GEMS/WATER (1992) variables include Total suspended solids, various Dissolved salts, Nutrients, and Organic matter.

3. Main problem however is, that the method gives no information on what parts of the landscape are most vulnerable. Additional fieldwork and other techniques are thus indispensable.

Therefore, this method is not very appropriate to get an accurate an precise picture of erosion.

b. Potential soil loss

Another approach is getting an overview of *potential* soil loss by using quantitative assumptions on the main variables contributing to soil loss. In the USA, the findings from thousands of plots were generalised in the *universal soil loss equation* (USLE).[6] The USLE equation is as follows:

$$A = (0.224)*R*K*L*S*C*P$$

where

A = soil loss in kg m^2 s^{-1}	S = slope gradient factor
R = rainfall erosivity factor	C = cropping management factor
K = soil erodibility factor	P = erosion control practice factor.
L = slope length factor	

The necessary variables can be derived from maps, photographs and satellite imagery, with additional field observations.

b.   replacement cost method

In assessing impacts of erosion, in several studies this method was used to estimate on-site costs of soil erosion. More specifically, this involved pricing the amount of commercial fertilisers that were used to replace lost nutrients in eroded material. This method does not take into account the off-site costs of soil erosion and the growth impact of loss of soil organic matter. The latter effects may be marked in sloping areas. In general, this method might go amiss by not recording all inputs and outputs of nutrient. Among the inputs, a sizeable amount of fertiliser might be lost in run-off and never reach the plant roots; among the outputs, the uptake by the crop is important.
[Ref.: nutrient loss approach: Costa Rica; refer to Repetto]

c.   Relative crop yield method

The difference between the Maximum Attainable Yield (MAY) and actual yield (in physical or monetary terms) is often used for a suitability assessment for a crop (Narain, 1977: 46-47). The MAY refers to yield on test plots on a model soil. Conversely, the MAY may be used to assess soil deterioration in terms of crop losses. Compared to the replacement cost method, MAY seems more significant, as crop loss incorporates not only erosion, but all soil deterioration (all environmental influences, for that matter).

Table 1. Classification of relative crop loss to assess soil deterioration

80% or more of MAY	Light soil deterioration
40 - 80% of MAY	Moderate soil deterioration
20 - 40% of MAY	Strong soil deterioration
<20% of MAY	Extreme soil deterioration

Adapted from Narain (1977: 47).

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[6] Generalised for global use in the modified universal soil loss equation (MUSLE).

4.3   Erosion control

It is important to make a distinction between the natural erosion rate, and the man induced erosion rate. Sustainability in this area may be interpreted as the requirement that natural erosion rates are not exceeded. The requirement will do as a first and general approximation; in areas where the natural erosion rate tends to be high (e.g. in young mountain ranges like the Himalayans and the Andes), and where population pressure is high, even the natural rate may be very detrimental for the functioning of an agricultural society, and considerable efforts should be made to keep erosion within bounds. Where these efforts are not made, agriculture can only bring a marginal livelihood. Societal stability and secure ownership rights are among the important incentives for farmers to invest in land maintenance.

Erosion control is the effort to make water deposit its load (Dupriez, 1992:151), and consists of three measures:

-    Splash control: Preventing direct rain impact by adequate vegetation cover, or by mulching.
-    Control of erosion by runoff: Reforestation, terracing, contour ploughing, strip cropping.
-    Promoting infiltration: Prevention of encrusted soils by tillage, retention of run-off, raised organic matter content of soil, and balanced fertiliser use (FADINAP, 1993).

In making economic assessments of the impact of degradation, various approaches have been used. Degradation costs[7] have been measured as: (i) the value of defensive expenditure on soil conservation works, drainage and irrigation systems, etc. required to prevent land degradation, (ii) the value of the lost yield[8], (iii) the replacement costs where the cost of additional inputs (fertilizer, etc.) needed to maintain the same level of yield is taken as a measure of the cost of soil degradation which can be equated to the quantity of lost soil nutrients (Stocking, 1986), (iv) taking an income approach whereby an estimate is made for reinvestment of a share of income from the land to maintain the same level of income (Lutz and El Seraphy, 1988), and (v) the cost of rehabilitating the plot to its former productive condition. Applied to soils, it would mean that a proportion of the profits made from exploitative land use which results in degradation of land, were reinvested in some other way, say in reclaiming coastal marshland to maintain the same level of income originating from the same land use. Each of these methods measure soil degradation from a different angle. Some of these methods can be used only for a particular type of degradation whereas some can be used universally. For example the fourth approach is not suitable to measure the cost of soil degradation when the water table of some of the land area has reduced.

Looking at the description given above for methods of valuation in SEEA and the commonly used methods by soil scientists, it can be concluded that the use of methods listed under the market valuation approach are generally not suitable for the measurement of the soil-degradation effect, except for the loss in productivity, which can be converted into volume of soil erosion in terms of requirement of additional inputs. Even in this case it may be difficult to find the capitalized value of the loss as the loss in soil is likely to effect productivity in the future. However, as a first approximation, it may be feasible to use this method to derive the first version of SEEA where conventional national accounts are reformatted to obtain a basic accounting framework of the SEEA.

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[7] For a more comprehensive discussion on methods for the valuation of soil resources, kindly refer to FAO et. al. (1994).

[8] This method is widely used as it is simple and applicable to all types of land degradation. In this method crop yields or other output are estimated for the non-degraded and degraded soil and then priced. The difference measures the value of lost production.

It is not sufficient to value the cost of installing soil conservation measures alone, followed by improved land management techniques, because in spite of this, one may still be left with a depleted soil. In the maintenance valuation approach, which is more appropriate for SEEA, when the soil is to be restored to its former condition then it is necessary to take into account three components to estimate depletion and degradation of soil: (a) cost of replacing nutrients through additional inputs to maintain level of productivity, (b) cost of replacing soil organic matter (and thereby restore structure which could be done, for example, by allotting part of the land to a green manure crop and foregoing production), and (c) cost of replacing the eroded soil. The first two components are relatively easy to estimate. The third component needs special consideration, because natural processes replace eroded soil very slowly and often require that the land remains fallow. At the same time, in these cases it is also expected that all soil conservation practices may continue. These methods are uneconomical in real life and would lead to exorbitant cost/value. Thus for the formulation of a comprehensive soil degradation account it would be necessary to take only the viable approaches in making economic and environmental plans.

It is suggested that for compiling a comprehensive estimate of soil degradation for a given area (country/region/sub-region) it would be appropriate to adopt "Maintenance valuation of environmental assets" which takes into account only changes in the quality of soil by accumulating related capital expenditure on the three components listed above in paragraph 12. The cost of the first two components (viz., replacing the lost soil nutrients and other organic matters) may be estimated by taking into account the fall in productivity and causative factors of soil degradation. Compilation of this cost may require use of soil maps to classify the total area into groups with the principal causes of soil degradation[9]. To account for the cost required for replacing soil nutrient etc.

the area may be further subdivided according to the degree of soil degradation, and for each subdivision we may also compile average productivity. Such data can generally be compiled by re-tabulation of the results of the crop estimation survey (Narain, 1995) which can at the same time also collect some minimum data on soil characteristics (FAO, 1995). With the help of such a tabulation it may be possible to make a more precise estimate per unit value of replacing soil nutrients. Details of areas affected by the principal causes of soil degradation will also provide a basis for estimating the cost of soil conservation measures required to be taken for protecting the soil from further degradation. The total cost can be apportioned between different years depending upon the estimated life of the asset created for soil conservation. This component can be taken in place of the third component (i.e. the cost of replacing eroded soil) for sustainable use of land.

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[9] For a comprehensive description of degree of soil degradation, the relative extent of soil degradation and causative factors of soil degradation please refer to An international methodology for an assessment of soil degradation land georeference soils and terrain database, L.R. Oldeman, in the Report of the Expert Consultation of the Asian Network on problem soils, Bangkok, 1993, FAO RAPA Publication: 1994/3

Box 2: Agroforestry

Addressing soil erosion by integrated agricultural practices

Soil degradation is a world wide problem that in some tropical areas has led to a lowered food production. Degradation is primarily due to population growth, demanding more land for agriculture. Fallow periods in slash & burn agriculture are thus shortened, and marginal grounds are taken in production. This leads to a reduction in soil fertility and soil erosion, reducing crop yields. Though the problem is well known, the solution is not simple. Use of fertilisers and soil conservation measures are often at odds with the socio-economic possibilities of small farmers in the tropics. Thus, short term impossibilities compete with long term necessities.

Research has shown that the integration of trees (or bushes/shrubs) in agricultural systems may contribute in reducing soil degradation. This research has mainly been carried out by ICRAF (International Centre for Research in Agroforestry), an international research institute based in Nairobi, with field stations all over the world.

Many agroforestry systems have been developed, varying from permanent and frequently cut back hedges with maize in between, to teak plantation, where in the first years food crops are grown as well.

The central tenet is that agroforestry systems are more productive and more sustainable than growing food crops alone. Trees have – in contrast to many crops – a positive effect on the physical, chemical and biological condition of the soil by adding nutrients and organic matter. Trees may limit soil fertility reduction by leaching or erosion, but they might also compete with food plants for the limited amount of water - a situation to be expected in areas with a rain fall of $< 1,000$ mm a year.

Choice for a certain tree (or shrub) is determined by the growth conditions, like soil and climate, and the qualities of the tree. In general the following trees are favoured: fixing atmospheric nitrogen (*Leguminosae* family), producing large quantities of biomass (wood, leaves), with an extensive root system, and leaves and roots do not contain toxic substances. A high wood production is of importance in areas where firewood is scarce, like in densely populated areas and great parts of the semi-arid tropics. An extensive and deep root system is important because it reduces competition for water with food crops, and because trees can take up nutrients from deeper soil layers that food crops do not reach. After cutting down the tree or shrub, and returning the leaves to the earth, nutrients become available for food crops. Leaves also add organic matter, which is essential to maintain soil fertility and structure for many tropical soils.

Erosion reduction with agroforestry systems is enhanced by planting trees or hedges along the contour lines of slopes. Run-off after heavy rains is retained en soil losses are thus reduced. Trees also offer soil cover and by interception reduce the erosive power of rain drops. Raising organic matter contents improves soil structure (porosity), lowering erosion. Ten to hundred fold erosion reductions have been recorded with agroforestry systems, in comparison with traditional monocultures without trees.

Agroforestry systems thus may offer a viable alternative to slash & burn agriculture, preventing further deforestation. However, socio-economic research in this field has received considerably less attention. The low input of capital would not stand in the way of acceptance by farmers. Whether agroforestry would be enough to raise food production in the tropics in a sustainable way is not very likely. To do so limited inputs of improved seeds, and fertilisers are needed in many parts of the tropics. Agroforestry would mean a more efficient use of these inputs, by maintaining or improving soil fertility and limiting erosion.

Source: Young (1997).

4.4   Wind erosion

Wind erosion is less well studied. Its main causes are disturbance of the vegetation cover (e.g. by overgrazing, inadequate cultivation practices and fires) and lowering of the water table (water use in excess of replenishment rate). Wind can then pick up soil particles and transport them away (*deflation*). Thus, at one place soil is lost, while at other places vegetation may be become buried. In addition, particle-laden wind can act as sand paper, and wear down vegetation, soil and rocks (*abrasion*). This exacerbates the effects of deflation.
Wind erosion is not always detrimental. Loess soils (quite extensive in e.g. the PR of China) owe their existence to peri-glacial [10] wind erosion, when under dry conditions fine particles were picked up from bare soils, and transported over large distances.
Wind erosion is closely linked to desertification, but certainly not limited to these areas. Areas particularly prone to wind erosion are loess soils and dryland soils. In dry regions, wind erosion is often strongly linked to water erosion, especially when seasonal rains follow long dry periods. On a dried out soil, this may result in strongly erosive surface flows (flash floods).

4.5   Some methods to assess and control wind erosion

To quantify wind erosion and its effects several methods seem feasible, comparable to those for water erosion discussed before. However, for the first two no references were found in literature. Only the third seems applicable, provided reference crop yields are established.

a.   Mass transport: loss by deflation; accumulation at other places (over-blowing).
b.   UWESLE, Universal Wind Erosion Soil Loss Equation.
c.   Relative crop yield method.

General responses against wind erosion are shelterbelts and windbreaks. Other measures are spraying the soil with stabilising compounds like oil products and shredded bark. Preventive measures consist of alleviating the pressures on the sparse vegetation in dry, wind erosion prone regions, e.g. lowering the amount of cattle per km^2.

4.6   Other types of degradation

A complete classification of soil degradation is given in Oldeman (1991), which is reproduced in the Annex. Below, because of their importance, two significant degradation types are discussed in more detail, salination and hazardous waste.

a.   Salination and waterlogging

Salt-affected soils generally occur in arid and semi-arid climates. In humid areas, the soluble salts originally present in soil material and those formed by weathering of minerals are carried down into the ground water and transported ultimately to the oceans. In humid regions salt-affected soils occur only when subjected to sea water intrusion in river deltas and other low lying land near the sea. (ESCAP,1990:11)
Salination is a natural process, e.g. when surface water or superficial groundwater runs out from a hill region into a low-lying dry area. The latter is e.g. found in northern Chile where groundwater from the Andes surfaces in the Atacama desert. Evaporation concentrates salts in the upper layer of the soil. Of more concern is salination caused by irrigation in agricultural areas. When water is

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[10] The cold and dry period after (or before) a glacial period.

applied in a measure not commensurate with local conditions, the upper layers of the soil will function as a wick, transporting groundwater upwards. Evapotranspiration then will lead to rising salt levels in the top soil, lowering crop yields.

An extreme case of salination is linked to water logging, heightening the water table to near the surface through an excess of infiltrated water. This may be the case in low-lying areas in irrigated land, or badly managed irrigation schemes. Water logging undermines the equilibrium of infiltration and discharge through evapotranspiration and ground water streams. With reduced drainage capacity, greater evaporation results in accumulation of salts in the upper soil horizons. On the other hand, insufficient application will also lead to salinisation, as salts are not leached down. (ESCAP, 1990: 6). The two extremes just described indicate that salination can be prevented through measured irrigation, requiring careful planning, land development, and monitoring of irrigation areas.

To assess the effects of salinisation, the potential crop loss method (MAY) discussed above may be used.

b. *Contamination by hazardous waste*

Hazardous waste is being produced in growing amounts as a necessary or wasteful by-product in the production of many products and chemicals. As treatment and safe dumping is often a very costly affair, it is attractive to get rid of it cheaply. This results in careless storage in basins, dumping mixed with normal garbage, and dumping in watercourses. For developed countries, export to developing countries may be an attractive possibility (in spite of the Basel Convention), leaving the receiving country with short-term money that could never possibly cover the costs of the long-term problem. Contaminated sites often start drawing attention when the consequences are already felt; remedial costs are often enormous, preventing a satisfactory solution.

Classification of hazardous wastes (and wastes in general) is a problematic issue. For classifications, refer to Batstone *et al* (1989), ECE (1989), and EC (1994). The latter is the most detailed and ambitious; the first follows the World Bank classification, which is quite broad, but might do for general purposes.
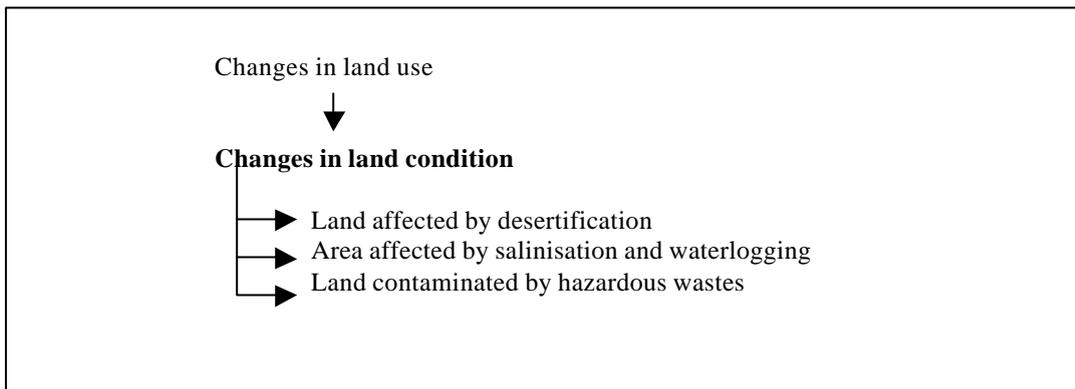
[To be expanded in conjunction with chapter 5, Waste]

5   STATISTICS

5.1   CSD indicators

It seems appropriate to start the discussion with the 'indicators' proposed by CSD (1996). The indicator "Changes in land conditions" may be regarded as an umbrella indicator encompassing all information on land and soil degradation. The indicator is defined as "Changes, disaggregated by type and geographic location, in the condition, suitability, and nature of the land resources. These may be of very different types including: physical soil condition, diversity or density of vegetation cover; thickness of topsoil; alkaline conditions; terracing; establishment of contour vegetation strips." (CSD, 1996). This heaping together of such a variety of changes makes it quite impracticable as an indicator; after all, no mention is made of a common denominator, nor seems one available.

Three types of degradation are given a separate indicator, as indicated in figure 1 below. It should be noted that the indicators are only based on the surface area affected. Without a qualification for the seriousness of the degradation, the indicators only have a limited value.

Figure 3: Relation of indicators proposed by CSD (1996)

Changes in land use

↓

Changes in land condition

→ Land affected by desertification
→ Area affected by salinisation and waterlogging
→ Land contaminated by hazardous wastes

[2.3.X Other approaches?]

5.2   Classifications

There is a great need for common classifications and methodology to organise existing data and to direct future efforts. [11] In 1991, a first world map on the status of human-induced soil degradation was published by ISRIC, in co-operation with FAO and UNEP (Oldeman *et al*, 1991). In preparation of the map, a general classification was developed, referred to as the GLASOD [12] classification. In the Annex, the classification of type, severity and cause has been reproduced. Methodology for storing and processing data into maps is provided by SOTER[13] (Van Engelen *et al*, 1993).

To reveal causes (pressures), land degradation information should be presented in conjunction with land use statistics. For the latter the standard classification as adopted by the CES might be used for a start (ECE, 1989). UNEP/FAO (1993) reports on work to further develop land use classifications. A major problem is that existing land use classifications are not homogeneous. In fact it is a mixture of *use* (function) categories (e.g. industrial areas, infrastructure) and *land cover* categories (e.g. wood, marsh land), the latter often without specification of (direct) uses. For example, in the case of wood additional information is needed to specify whether a wood area is (mainly) used for production, for conservation, or recreation.

Physical degradation (water and wind erosion) can - to a certain extent - be observed from the air, though early stages will escape such inspection. Chemical degradation, and physical deterioration like waterlogging can only be observed and assessed in the field.

For developing countries, merely recording of actual soil degradation will not do. To inform policy makers, potential soil degradation (vulnerability) should complement data on current degradation. Such an assessment might start in areas under severe current threat or areas considered for development; ideally, it should be part of an Environmental impact assessment (EIS). Long term costs of exploiting unsuitable land in most cases exceed yields. To this end, it may be important to make computations on cases of land rehabilitation or losses of suitable land.

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[11] National and regional advantages of common methodology are listed in FAO/RAPA, 1994: 17.

[12] GLASOD = **Gl**obal **A**ssessment of **So**il **D**eterioration.

[13] Global **so**ils and **ter**rain digital database.

5.3   Land use/cover data

Figure 9 above shows that land use/cover data are basic to statistics on land degradation.
Land use data are published for virtually all countries. [14] Thus, basic methodology and skills may
thus be assumed available. For the purpose of environment statistics the main problem is the
usefulness of existing statistics to assess environmental problems. This may partly be due to
currently used classifications, partly to opportunities lost in presentation. In this regard, a problem
not to be overlooked is the loss of agricultural land to urbanisation.

5.4   Data types

Several types of data may be available or used to assess changes in land condition.
-    Census data: Agriculture (e.g. surface area; crop types).
-    Sample surveys: e.g. on soil quality.
-    Administrative data: land registry (cadastre) mapping.
-    Soil maps, geological maps, physiographic maps (slope length & steepness).
-    Aerial photography, satellite imagery (= remote sensing) + additional ground observations.
-    Current and prospective soil loss data computed with USLE.

5.5   PSR scheme

Putting the indicators discussed so far in the PSR scheme might their relation. Some additional
indicators were included for discussion.

Pressure
-    Population.
-    Selected activities: e.g. Agriculture, Forestry.

State
-    Land use/land cover data
-    Changes in land condition and subsumed indicators
-    Protected areas (Protected forests).
-    Satellite derived vegetation index (CSD, 1996: 260-262)
-    Data on soil type, slope steepness and length, rainfall, etc. (for use in USLE).
-    Crop losses (MAY).

Responses
Mainly monetary data:
-    Prevention & restoration costs;
-    Replacement costs (soil minerals);

5.6   Data sources

Local:
-    Ministry of agriculture.
-    National planning/ Land management institute.
-    Soil science institutes.

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[14] Notable (temporary) exceptions seem to be countries who were part of the former USSR   (see *World
Resources 98-99*).

International:
Soil degradation is as old as the world, but systematic attention to its extent and impact is relatively new. Hence, classifications and methodology are far from consolidated. When work on soil degradation is started up or expanded it is advisable to contact the international institutes directly involved in the development of classifications, methodology, and data collection & processing.

- FAO, Rome, or regional adviser.
- UNEP, Nairobi, or regional office.
- International Soil Reference and Information Centre (ISRIC), Wageningen, Netherlands.

5.7   Discussion

To identify causes of degradation and appropriate responses a linkage to Land use and land cover statistics seems desirable. Unfortunately, these statistics are often not well developed and not consistent; Multiple land use is not recorded. Furthermore, existing land cover and land use data tend to be rather static, and may fail to capture important changes (e.g. change of crop).
The best general and cost-effective approach seems to be remote sensing, validated by ground truthing. However, this way change in land cover is be more easily detected than change in use. Even then, the question remains whether change in cover is part of a real and permanent change or part of a cycle (e.g. crop rotation, forest production rotation).
For planning purposes not only actual, but also potential degradation should be assessed. Such an approach might lead to "potential use" or "constraints" mapping, an important tool in degradation prevention and mitigation.

5.8   What is to be done?

Some general steps are suggested.

1. Compare currently available data to national needs.
2. As needs may vary per region, it seems useful to identify regions (with like climatic conditions, soil types, ecosystems, agricultural practices, etc.). The World map may be consulted for this.
3. Select priority regions and degradation types.
4. Transform available data using GLASOD classifications.
5. Generation of missing data.
6. With sufficient skill gained, other regions or the whole country might be covered.

5.9   Who is to carry out the work?

Even when the NSS is involved in producing land use statistics, the questions remains whether they should act as the lead institute in producing soil degradation data and maps.

1. Application and adaptation of degradation classifications, and local adaptations/aggregations thereof, requires highly specialised skills.
2. So does the possible use of remote sensing and storage in GIS systems.
3. Involvement also might depend on the actual status and possibilities of the NSS. Is the Bureau directly linked to policy makers (e.g. under the PM's Office, or the Planning Commission) or more remote to it?
4. NSS certainly should be involved in adding selected data to a (GIS) database: population, economic activities, agricultural census, etc. In addition, in disseminating aggregated results NSS might make important contributions.

5. In producing the additional (economic) data mentioned, the NSS might have a more prominent role. E.g., it might be considered to ask additional questions on actual costs made by farmers for soil protection in the Agricultural census. Data on MAY might be derived from statistics on crop yields.
6. Agriculture is the main cause of large scale erosion and soil deterioration. Hence agricultural statistics seems the natural framework for these data.

5.10   Conclusions and recommendations

1. It seems unlikely and undesirable that work on soil degradation (state) is taken up by the NSS alone. The expertise to collect, process and analyse data will hardly ever be available in house. It might be more fruitful when a specialised institute assumes the leading role.
2. Available methodology has no official status, but is rapidly being developed at an international level. It is recommended to follow this lead, and make classifications for national use directly convertible into GLASOD. For storage of data and production of maps SOTER is recommended.

ANNEX: GLASOD CLASSIFICATIONS (OLDEMAN, 1991)

Table A. Type of soil degradation

TYPE		
W	**Water erosion**	
Wt	Loss of topsoil	
Wd	Terrain deformation/mass movement	
Wo	Off-site effects	
	Wor	Reservoir sedimentation
	Wof	flooding
	Woc	Coral reef and seaweed destruction
E	**Wind erosion**	
Et	Loss of topsoil	
Ed	Terrain deformation	
Eo	Over-blowing	
C	**Chemical deterioration**	
Cn	Loss of nutrients or organic matter	
Cs	Salinisation	
Ca	Acidification	
Cp	Pollution	
Ct	Acid sulphate soils	
Ce	Eutrification	
P	**Physical deterioration**	
Pc	Compaction, sealing and crusting	
Pw	Water-logging	
Pa	Lowering of water table	
Ps	Subsidence of organic soils	
Po	Other physical activities such as mining and urbanisation	
B	**Degradation of biological activity**	

Table B. Degree of degradation

DEGREE OF DEGRADATION	
Light	Somewhat reduced agricultural productivity
Moderate	Greatly reduced agricultural productivity
Strong	Unreclaimable at the farm level
Extreme	Unreclaimable and impossible to restore

Note [15]

Table C. Causative factors in soil degradation

CAUSATIVE FACTORS	
f	Deforestation and removal of natural vegetation
g	Overgrazing
a	Agricultural activities
e	Overexploitation of vegetation fore domestic use
i	(Bio)industrial activities

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[15] Generalised degree of degradation as used for the World map. ISRIC (1988) gives separate classifications for water erosion, wind erosion, salinisation, and nutrient decline.

DEFINITIONS OF GLASOD CLASSIFICATIONS

Types of soil degradation are represented in the database by a two-letter code, the first capital letter giving the major degradation type, the second lower case letter giving the subtype. In some cases a third *lower case* letter can be used for further specification (see examples below). Most of the following codes are the same as the ones used on the GLASOD map, but some extra ones have been added, and for others the definition has been changed slightly.

Wt   *Definition:* loss of topsoil by sheet erosion/surface wash
Description: a decrease in depth of the topsoil layer (A horizon) due to more or less uniform removal of soil material by run-off water
Possible causes: inappropriate land management especially in agriculture (insufficient soil cover, unobstructed flow of run-off water, deteriorating soil structure) leading to excessive surface run-off and sediment transport
6 Assessment of soil degradation in South and Southeast Asia
Although erosion of upstream areas may lead to pollution (with pesticides etc.), this is considered as an 3 off-site effect of erosion rather than a type of pollution.

Wd   *Definition:* "terrain deformation" by gully and/or rill erosion or mass movements
Description: an irregular displacement of soil material (by linear erosion or mass movements) causing clearly visible scars in the terrain
Possible causes: inappropriate land management in agriculture forestry or construction activities, allowing excessive amounts of run-off water to concentrate and flow unobstructed

Wo   *Definition:* off-site effects of water erosion in up-stream areas
Description: Three subtypes may be distinguished: sedimentation of reservoirs and waterways (Wos), flooding (Wof), and pollution of water bodies with eroded sediments (Wop)
Possible causes: see Wt and Wd

Et   *Definition:* loss of topsoil by wind action
Description: a decrease in depth of the topsoil layer (A horizon) due to more or less uniform removal of soil material by the wind
Possible causes: insufficient protection by vegetation (or otherwise) of the soil against the wind; insufficient soil moisture; destruction of soil structure

Ed   *Definition:* "terrain deformation"
Description: an irregular displacement of soil material by wind action, causing deflation hollows, hummocks and dunes
Possible causes: as with Et

Eo   *Definition:* off site effects of wind erosion
Description: covering of the terrain with wind borne soil particles from distant sources ("overblowing")
Possible causes: see Et and Ed

Cn *Definition:* Fertility decline and reduced organic matter content
Description: a net decrease of available nutrients and organic matter in the soil
Possible causes: a negative balance between output (through harvesting, burning, leaching, etc.) and input (through manure/fertilizers, returned crop residues, flooding) of nutrients and organic matter

Cp *Definition:* pollution
Description: a distinction is made between "contamination", indicating the mere presence of an alien substance in the soil without significant negative effects, and "pollution", signifying soil degradation as a consequence of location, concentration and adverse biological or toxic effects of a substance. In this context only the latter is relevant. Both local source pollution (waste dumps, spills, factory sites, etc. (Cpl)) and diffuse or airborne pollution (atmospheric deposition of acidifying compounds and/or heavy metals (Cpa)) are considered under this category.
Assessment of soil degradation in South and Southeast Asia 7
Possible causes: draining of soils containing pyrite which will produce very acid sulphate soils ("cat-clays" (Cta)). Planting of acidifying vegetation (e.g. fir) may also lower the soil pH (Ctf). NB acidification by airborne components is considered as pollution!

Ce *Definition:* Eutrophication
Description: An excess of certain soil nutrients, impairing plant growth
Possible causes: Imbalanced application of organic and chemical fertilizer resulting in excess Nitrogen, Phosphorus; liming.

Pc *Definition:* compaction
Description: deterioration of soil structure by trampling by cattle or the weight and/or frequent use of machinery
Possible causes: repeated use of heavy machinery, having a cumulative effect. Heavy grazing and overstocking may lead to compaction as well. Factors that influence compaction are ground pressure (by axle/wheel loads of the machinery used); frequency of the passage of heavy machinery; soil texture; soil moisture; climate.

Pk *Definition:* sealing and crusting
Description: clogging of pores with fine soil material and development of a thin impervious layer at the soil surface obstructing the infiltration of rainwater
Possible causes: poor soil cover, allowing a maximum "splash" effect of raindrops; destruction of soil structure and low organic matter.

Pw *Definition:* waterlogging
Description: effects of human induced hydromorphism (i.e. excluding paddy fields)
Possible causes: rising water table (e.g. due to construction of reservoirs/irrigation) and/or increased flooding caused by higher peakflows.

Ps *Definition:* lowering of the soil surface
Description: subsidence of organic soils, settling of soil
Possible causes: oxidation of peat and settling of soils in general due to lowering of the water table (see also Pa); solution of gypsum in the sub-soil (human-induced?) or lowering of soil surface due to extraction of gas or water

Pu *Definition:* loss of productive function
Description: soil (land) being taken out of production for non-bio-productive activities, but *not* the eventual "secondary" degrading effects of these activities.
Possible causes: urbanization and industrial activities; infrastructure; mining; quarrying,etc.

Pa *Definition:* aridification
Description: decrease of average soil moisture content
Possible causes: lowering of groundwater tables for agricultural purposes or drinking water extraction; decreased soil cover and reduced organic matter content

Sn Stable under natural conditions; i.e. (near) absence of human influence on soil stability, and largely undisturbed vegetation. NB: some of these areas may be very vulnerable to even small changes in conditions which may disturb the natural equilibrium.

Sh Stable under human influence; this influence may be passive, i.e. no special measures had or have to be taken to maintain stability, or active: measures have been taken to prevent or reverse degradation.

W "Wasteland": land without vegetation and with (near) absence of human influence on soil stability, e.g. deserts, high mountain zones. Natural soil degradation processes may occur!
Possible causes: bio-industrial sources, dumping, spillage 3

Cs *Definition:* salinisation/alkalinization
Description: a net increase of the salt content of the (top)soil leading to a productivity decline.
Possible causes: a distinction can be made between salinity problems due to intrusion of seawater (which may occur under all climate conditions: Css) and inland salinisation, caused by improper irrigation methods and/or evaporation of saline groundwater (Csi).

Ct *Definition:* Dystrification
Description: the lowering of soil pH through the process of mobilizing or increasing acidic compounds in the soil.

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